North Slope

Rapid Ecoregional Assessment

Memorandum III: Methods (Final)

Prepared for:

Department of the Interior
Bureau of Land Management
Rapid Ecoregional Assessments

Submission Date:

31 March, 2014

Submitted to:

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Acronyms used in this document:

ACEC	Area of Critical Environmental Concern
ADF&G	Alaska Department of Fish and Game
ADNR	Alaska Department of Natural Resources
AKGAP	Alaska Gap Analysis Program
AKNHP	Alaska Natural Heritage Program
ALFRESCO	Alaska Frame-based EcoSystem Code
AMT	Assessment Management Team
AWC	Anadromous Waters Catalog
BLM	Bureau of Land Management
BPS	Biophysical Setting
CA	Change Agent
CE	Conservation Element
ESRI	Environmental Services Research Institute
GCM	Global Circulation Model
GIPL	Geophysical Institute Permafrost Lab
HUC	Hydrologic Unit Code
ISER	Institute of Social and Economic Research
LCM	Landscape Condition Model
MAGT	Mean Annual Ground Temperature
MQ	Management Question
NHD	National Hydrography Dataset
NLCD	National Land Cover Database
NPR-A	National Petroleum Reserve-Alaska
NOS REA	North Slope Rapid Ecoregional Assessment
REA	Rapid Ecoregional Assessment
SNAP	Scenarios Network for Alaska and Arctic Planning
Tech Team	Technical Team
TEK	Traditional Ecological Knowledge
TNC	The Nature Conservancy
USGS	United States Geological Survey
UA	University of Alaska
USFWS	United States Fish and Wildlife Service

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Introduction

As part of the Bureau of Land Management's (BLM) landscape approach to the management of public lands, the BLM and collaborators are conducting Rapid Ecoregional Assessments (REAs) in the western United States, including Alaska. To address current problems and future projections at the landscape level, the REAs are designed to transcend management boundaries and synthesize existing data at the ecoregion level (or in the case of Alaska, combinations of generally similar ecoregions).

Phase I Objectives

Phase I, the Pre-Assessment Phase of the REA, includes three tasks that are prerequisite to finalizing the components of the Work Plan and continuing to Phase II, the Assessment Phase. These include:

Task I. Selection of MQs, CEs, and CAs and the development of a Conceptual Ecoregional Model.

Task II. Collection and evaluation of data layers necessary to conduct the assessment, and the identification of current data gaps.

Task III. Development of an approach to analyses, including methods, models, and tools.

The Task I Memorandum discussed the selection of Management Questions (MQs), Conservation Elements (CEs), and Change Agents (CAs) for the North Slope REA.

The Task II Memorandum discussed the datasets that may potentially inform the analyses of CEs, CAs, and MQs and identified current data gaps. Datasets were listed in a series of tables. The goal of data discovery was to obtain source datasets that would then allow us to move forward with the identification of methods in Task III.

Memoranda I and II are available on the Alaska Natural Heritage Program (AKNHP) website along with other materials related to the North Slope REA.

Memorandum III Objectives

Memorandum III summarizes methods of analysis proposed for MQs, CEs, and CAs.

The objectives of Task III are:

1. List the CEs to be addressed, describing the approaches and categories in which they will be treated.
2. Describe specific assessment methods to address MQs.
3. Build prototype Conceptual Models for CEs with a suite of key ecological attributes identified. Each of these attributes needs one or more associated indicators, including a description of acceptable range of variation for each key ecological attribute.
4. Identify, describe, and recommend models, methods, and tools for characterizing CEs, CAs, and their interactions.
5. Evaluate methods and tools for their ability to perform as intended.

Review of Selected CEs, CAs, and MQs

A summary of all CEs and CAs selected for analysis in the North Slope REA and the number of MQs by disciplinary topic is provided in Table 1. Additional details on CEs and CAs are provided within their corresponding sections. A list of all MQs is provided in Table 2.

Table 1: CEs and CAs with number of associated MQs in parentheses.

Coarse-Filter CEs		Fine-Filter CEs		CAs	
Terrestrial (5)	**Aquatic (2)**	**Terrestrial (4)**	**Aquatic (2)**	**Category**	**Subcategory**
Coastal Plain Moist Tundra	Deep connected lakes	Caribou (*Rangifer tarandus*)	Broad whitefish (*Coregonus nasus*)	Abiotic Factors - Climate	Precipitation
					Temperature
Sand Sheet Moist Tundra	Shallow connected lakes	Nearctic brown lemming (*Dicrostonyx trimucronatus*)	Dolly Varden (*Salvelinus malma*)		Thaw Date
					Freeze Date
Coastal Plain Wetland	Large streams	Arctic fox (*Vulpes lagopus*)	Arctic grayling (*Thymallus arcticus*)		Cliomes
				Abiotic Factors - Fire (1)	Return Interval
Sand Sheet Wetland	Small streams	Lapland longspur (*Calcarius lapponicus*)	Burbot (*Lota lota*)		Vegetation Response
				Abiotic Factors - Permafrost (1)	Ground Temperature
Foothills Tussock Tundra		Raptor concentration areas	Chum Salmon (*Oncorhynchus keta*)		Active Layer Thickness
				Invasive Species	
Floodplain Shrubland		Willow ptarmigan (*Lagopus lagopus*)		Anthropogenic Factors (2)	Subsistence
Tidal Marsh		Greater white-fronted goose (*Anser albifrons*)			Natural Resource Extraction
Marine Beach and Beach Meadow					Transportation and Communication Infrastructure
Alpine Dwarf Shrub					Recreation
					Energy Development

MQs reflect critical resource and management concerns in the region, and focus the REA on those concerns. The Assessment Management Team (AMT) for the North Slope REA prioritized a list of 20 MQs through an iterative scoring process (Table 2). Throughout this memorandum, MQs will be referenced by 3-digit alpha-numeric codes provided in Table 2 (e.g., AB 1).

Table 2: MQs selected by the AMT.

Abiotic Factors	
AB 1	Is the fire regime changing on the North Slope and what is the likely future fire regime (or range of regimes) based on climate projections and current knowledge of the relationships between climate and fire?
AB 2	How will permafrost change spatially and temporally over the next two decades?
Anthropogenic Factors	
AP 1	What physical and perceptual limitations to access to subsistence resources by local residents are caused by oil/gas activities?
AP 2	How are oil, gas, and mineral development on the North Slope impacting near- and far-field air quality, with particular emphasis on communities and "sensitive class 2" areas such as ANWR, Gates, Noatak?
Aquatic Coarse-Filter CEs	
AC 1	How does water withdrawal from lakes for oil and gas activities (year-round industrial and domestic use and winter operations) affect lake water quantity and water quality, outflow/stream connectivity, and down-basin stream habitat?
AC 2	How does oil and gas infrastructure (e.g. roads, pads, pipeline), both permanent and temporary, affect fish habitat, fish distribution, and fish movements?
Aquatic Fine-Filter CEs	
AF 1	What are baseline characteristics and trends in fish habitat (lakes and streams), fish distribution, and fish movements?
AF 2	What are the measurable and perceived impacts of development on subsistence harvest of fish?
Aquatic and Terrestrial Fine-Filter CEs (non-spatial questions involving multiple CEs)	
AT 1	What parameters can help measure impacts from anthropogenic activities independently of natural cycles and vice versa?

AT 3	What additional contaminants baseline data are needed for fish, birds, marine and terrestrial species, particularly those that affect the health and safety of subsistence foods?
Terrestrial Coarse-Filter CEs	
AT 2	What potential impacts will oil/gas exploration and development have on CE habitat?
TC 1	What are the impacts of oil/gas development (i.e. gravel pad and road construction; pipeline construction) on vegetation and hydrology? (Known impacts include burial, dust, saline runoff and altered soil moisture.)
TC 2	What are the changes in habitat and vegetation related to changing permafrost conditions, and what will these changes mean to wildlife and habitats?
TC 3	How will changes in precipitation, evapotranspiration, and active layer depth alter summer surface water availability in shallow-water and mesic/wet tundra habitats and how reliable are these projections?
TC 4	What are the expected changes to habitat as a result of coastal erosion and coastal salinization?
TC 5	How is climate change affecting the timing of snow melt and snow onset, spring breakup and green-up, and growing season length?
Terrestrial Fine-Filter CEs	
TF 1	What are the baseline data for the species composition, numbers of individuals, vegetation type used, and change in numbers/species composition of landbirds and their habitat over time?
TF 2	What are caribou preferences for vegetation communities? Where do these vegetation communities exist?
TF 3	What are the measurable and perceived impacts of development on subsistence harvest of caribou?
TF 4	What are caribou seasonal distribution and movement patterns and how are they related to season and weather?

Reporting Units and Scale

As proposed in Memorandum I, reporting units for this analysis will be at the landscape level in scale and intent. The BLM has specified that results should be reported at the 5th level 10-digit hydrologic unit code (HUC), and that raw data should be provided at 30 m (or some derivative of 30 m) grid cell resolution or other native resolution as appropriate. Given the resolution of most available data in Alaska, raw data will be provided at 60 m grid cell resolution, when possible, and results will be reported at the 5th level HUCs, when appropriate. HUC boundaries in the ecoregion are presented in

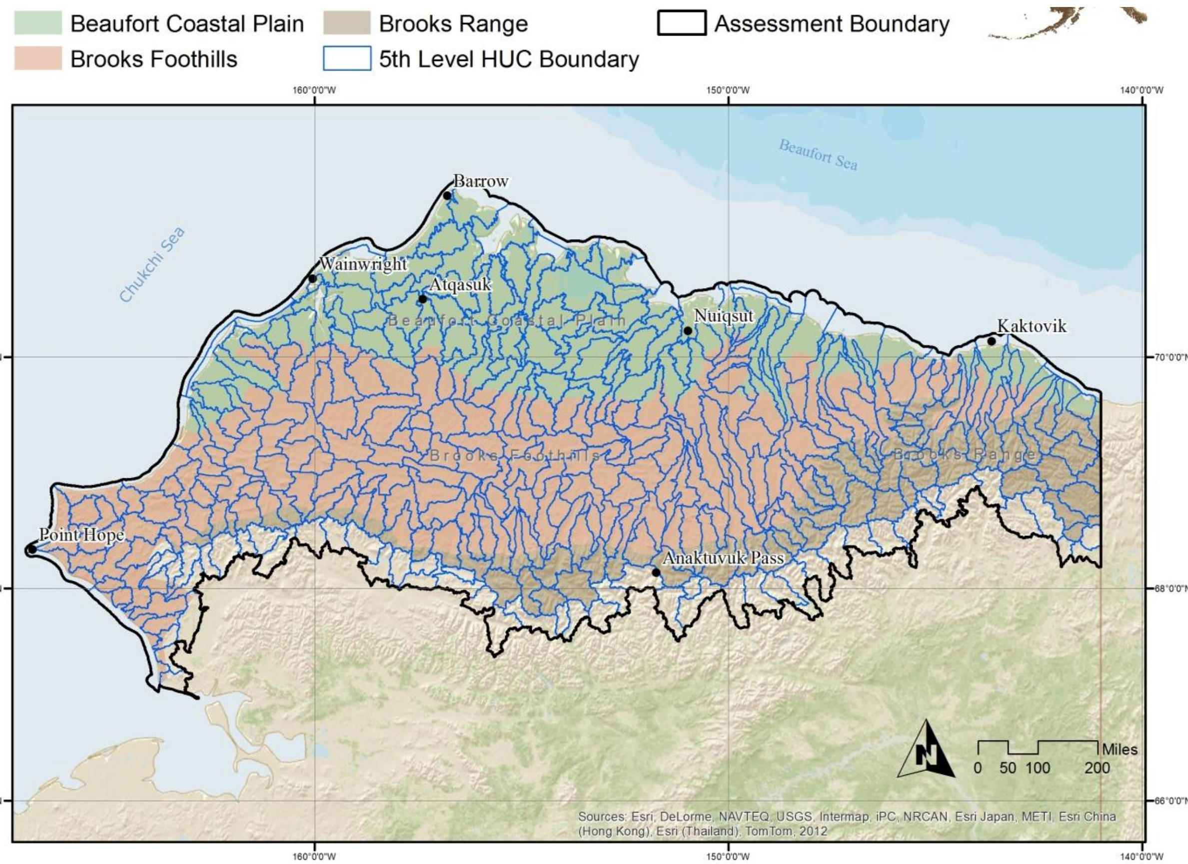


Figure 1. The BLM acknowledges that most climate data are only available at a coarser scale. Alaska has access to future climate data at 771 m grid cell resolution. The 771 m grid cell resolution for climate data was proposed and accepted by the Technical Team during the NOS REA Data Discovery webinar. Likewise, climate-linked permafrost data are available at 1 km resolution.

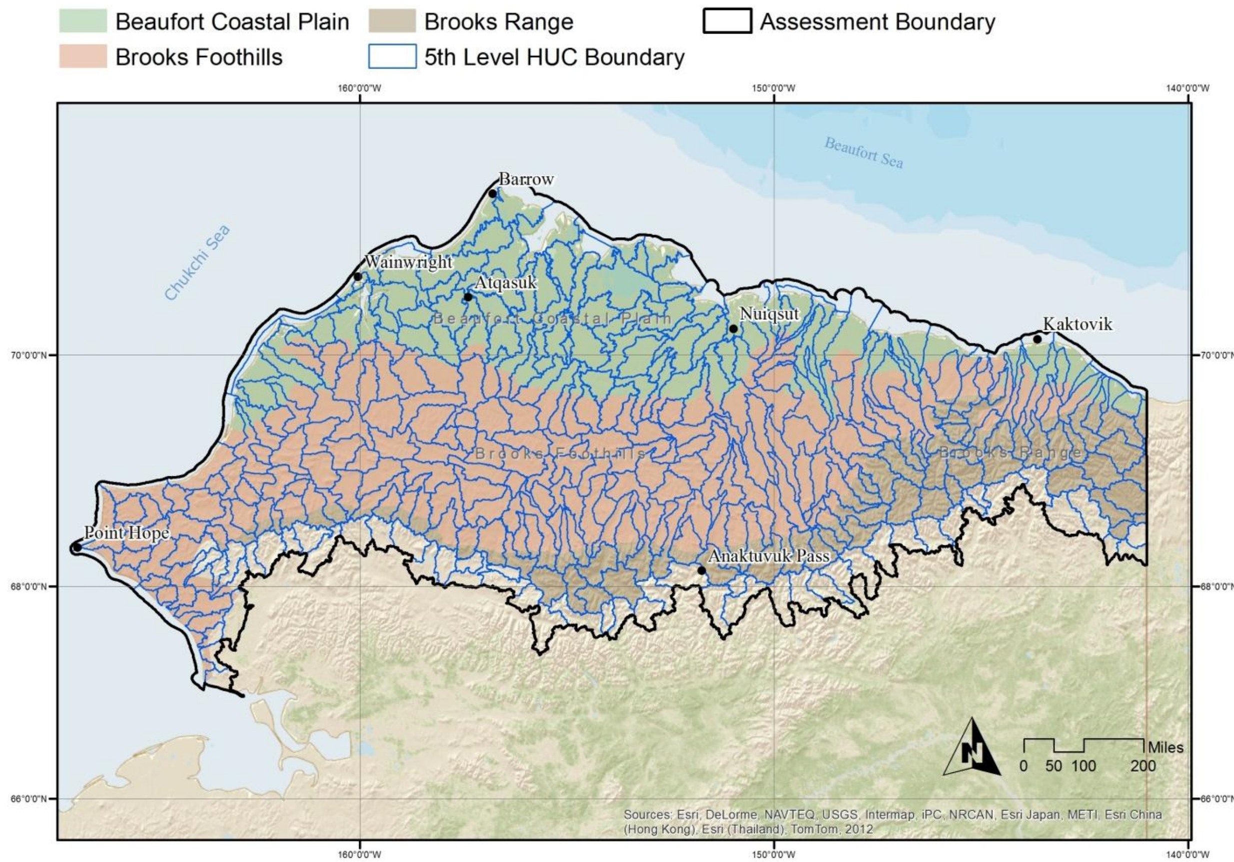


Figure 1: 5th-Level HUCs for the North Slope REA.

Chapter 1: Management Questions

In this chapter, we provide detail on each of the twenty selected Management Questions (MQs) including background information, desired products, applicable datasets, modeling methods and expected outputs, and challenges or limitations. Our intent is to provide transparency in the process, and to clarify how we hope to address each questions with respect to interpretation, context, scale, and detail.

Process Models

While conceptual models help inform the ecological relationships between ecosystem components, drivers, and processes, **process models** illustrate computational relationships or logical decisions within the context of a spatial or mathematical model to produce an output. Process models diagram data sources, geoprocessing procedures, and workflows, providing analytical transparency and allowing for repeatability of processes and methodologies in the future.[1] Process models have been developed for each MQ and are described below.

Each **process model** will contain the following:

1. A graphical diagram illustrating key elements (datasets representing key attributes of CEs, CAs, and MQs) and procedures in the computational process, the relationship among them, and the flow of information and analyses. Specific inputs, outputs, and processes are identified within boxes in the diagram with procedural relationships indicated by arrows.
2. Descriptive text explaining the graphical diagram to aid interpretation for the reader.

Methods for developing process models for all MQs are similar: source datasets are computationally or spatially related to produce outputs that are further related to produce final products. Process models are diagrammed according to the conventions in Figure 2 below.[1]

[1] Bryce et al. 2012

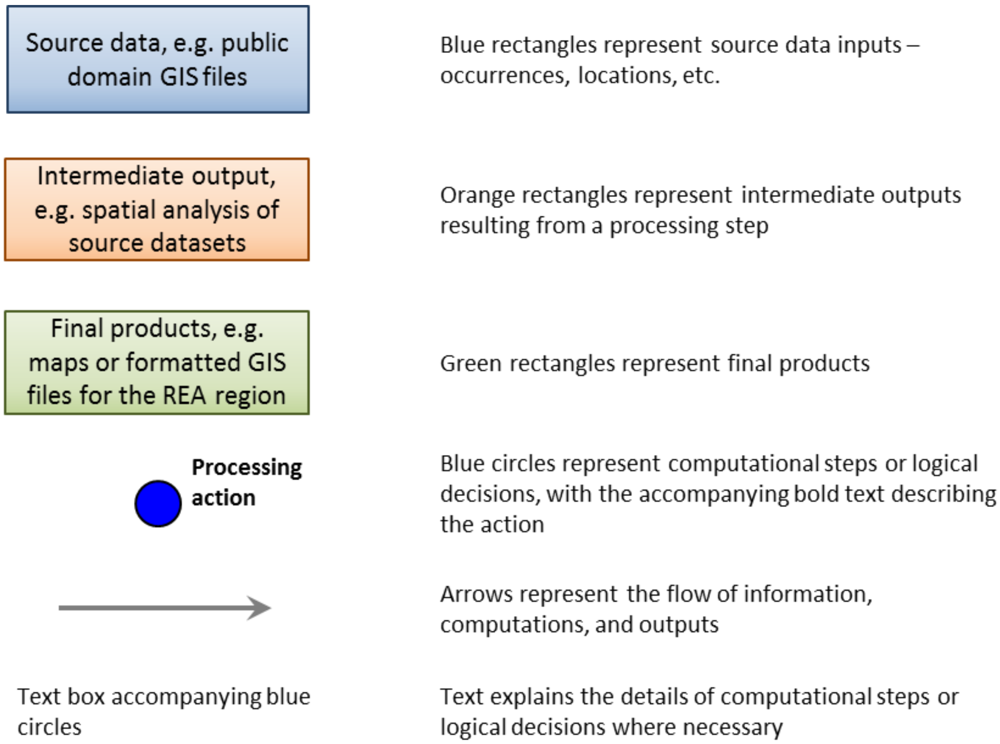


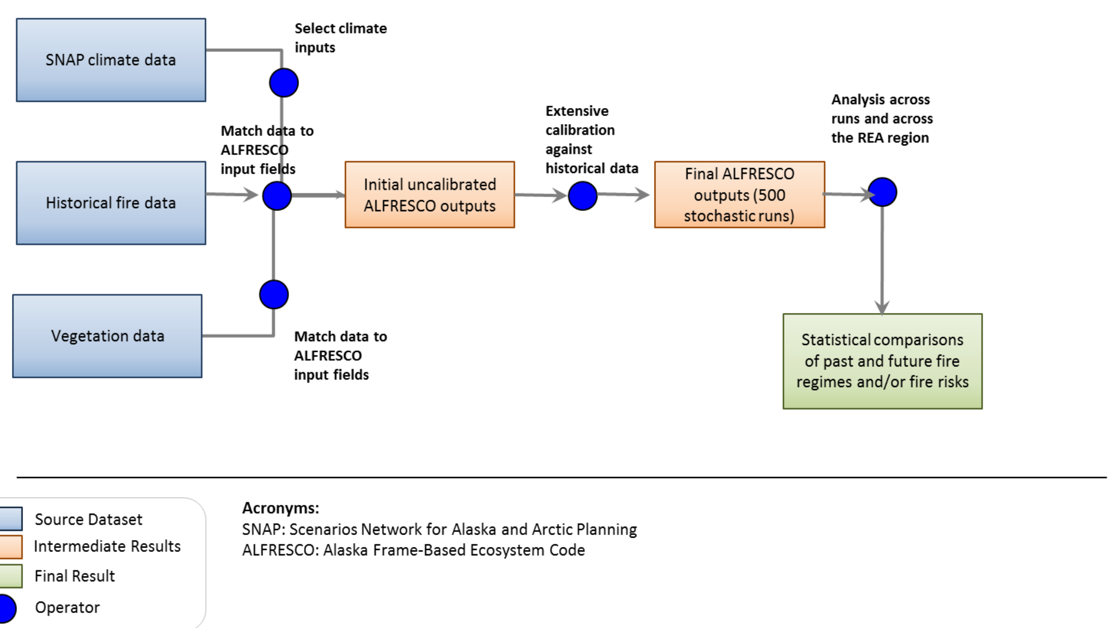
Figure 2: Conventions for Process Models.

MQ AB 1: Is the fire regime changing on the North Slope and what is the likely future fire regime (or range of regimes) based on climate projections and current knowledge of the relationships between climate and fire?

Description:

Although fire is an integral – and relatively common – element of forested ecosystems in boreal Alaska, fire has historically been a relatively rare occurrence on the North Slope and in tundra habitats in general. The Anaktuvuk River fire in 2007, which burned over 400 square miles of tundra, was an unprecedented exception. The ecological changes wrought by this fire – including immediate habitat destruction, longer-term habitat change, and overall successional dynamics – are of great interest to ecologists, land managers, and subsistence resource users. Based on this fire, and on predictions of how changing climate may make tundra systems more fire-prone, research and modeling related to tundra fires has increased in the past few years. This question addresses the pressing issue of how fire may affect the North Slope in the future. Datasets representing historical/current fire must be compared to projections of future fire frequency. Projections are based on models of both future climate and interactions between fire, climate and vegetation. Answers to this question will be expressed in terms of regional fire risks for given time periods.

Process Model:



Acronyms:
SNAP: Scenarios Network for Alaska and Arctic Planning
ALFRESCO: Alaska Frame-Based Ecosystem Code

Methods:

The Scenarios Network for Alaska and Arctic Planning (SNAP) has been working to improve and expand the Alaska Frame-based Ecosystem Code (ALFRESCO) model, a stochastic spatially explicit fire model originally designed for boreal systems, such that it can reliably predict the future frequency of tundra fires, and associated vegetative change. We will use existing SNAP climate projections of historical fire data from the BLM and other sources[2] and vegetation data as inputs to the SNAP/ALFRESCO model. The vegetation data used in ALFRESCO will be derived by reclassifying the 1990 AVHRR vegetation classification (http://agdcftp1.wr.usgs.gov/pub/projects/fhm/vegcls.tar.gz) and the 2001 National Land Cover Database vegetation classification (http://www.mrlc.gov) into appropriate vegetation classes.

In order to ensure model reliability, the models must be carefully calibrated over many thousands of runs, using a historical spin-up period. The 'spin-up' phase of the modeling generates multiple different initial landscape conditions (vegetation distribution and age structure) at 1860 by using random permutations of historic climate observations from (Climate Research Units) CRU and Potsdam Institute for Climate Impact Research (PICIR) datasets. These landscapes provide the initial (1860) conditions that ALFRESCO uses as input for the simulations. The purpose of the 'spin-up' phase is to produce a simulation landscape with realistic patch size and age-class distributions that are generated over multiple fire cycles of hundreds of years. By performing this historical spin-up, modelers can determine how closely the outputs match actual fire conditions, statistically, and adjust the model to better match reality. Through an iterative process, the best possible calibration can be achieved.

Challenges:

These calculations are particularly challenging for tundra, where limited past fire occurrences yield limited calibration data. Because fire is so variable across time and space, outputs (spatial fire risk for given time periods) can only be considered across broad areas, such as 3rd level HUCs not at the 1km resolution of ALFRESCO.

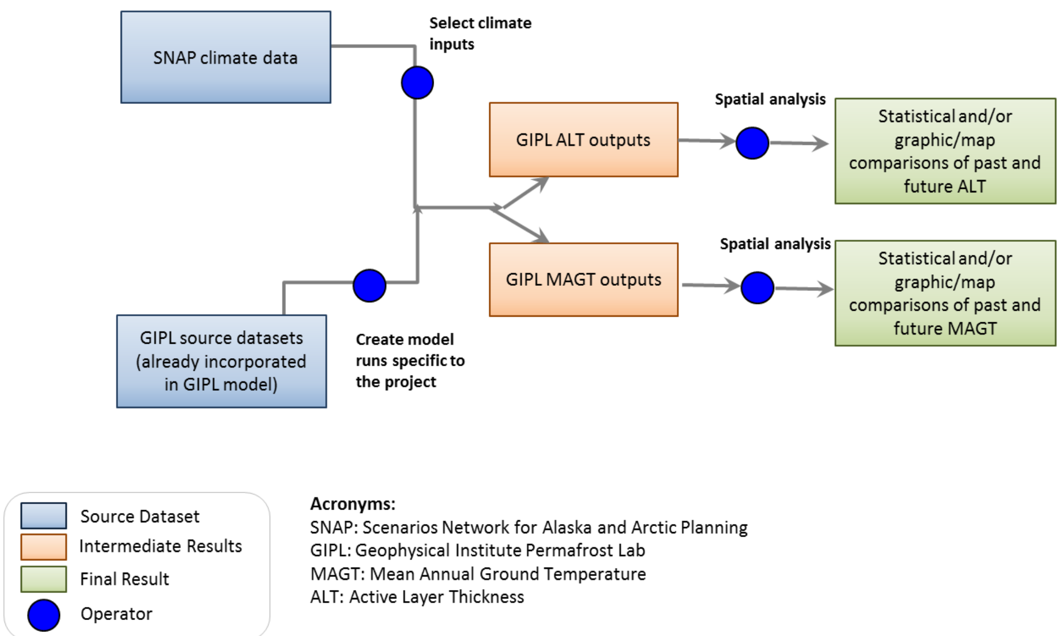
[2] BLM AFS 2014, Kasischke et al. 2002

MQ AB 2: How will permafrost change spatially and temporally over the next two decades?

Description:

Permafrost underlies almost all of the North Slope, although it is discontinuous in some areas. Permafrost may be considered in terms of presence/absence, but may also be considered more broadly in terms of the depth of frozen ground and seasonal depth of thaw (active layer thickness, ALT) and the mean annual ground temperature (MAGT). Characteristics of ALT and MAGT profoundly affect hydrology, ground stability, and ecosystem dynamics. Changing climate is likely to alter this dynamic. This question asks how and when this change may occur. Answers will be presented spatially, in map form, and by fifth level HUC.

Process Model:



Methods:

SNAP has been working with researchers at UAF's Geophysical Institute Permafrost Lab (GIPL) to create combined climate/permafrost spatial models linked to GIPL's permafrost model. The GIPL model already includes data on vegetation, soil type, and other key elements that affect soil thaw and freeze cycles. SNAP models add a climate component, in order to make predictions about changes to ALT and MAGT.

Challenges:

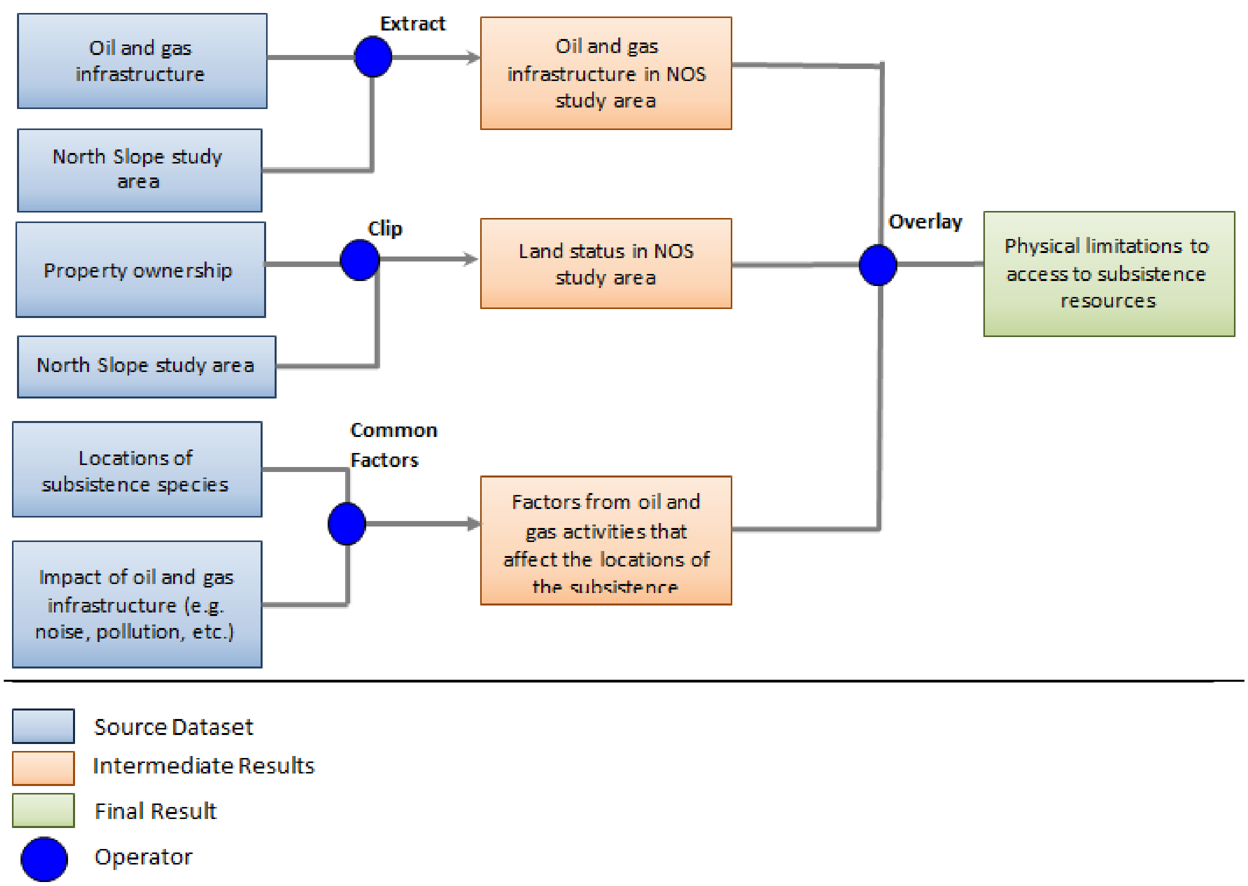
Uncertainty is inherent to both the GIPL and SNAP models, due to limited ability to ground-truth – although the best available data from climate stations, remote sensing, and bore-holes are incorporated. The combined SNAP/GIPL model offers projections only at a resolution of approximately 1 km. Many effects of permafrost change occur at a finer scale.

MQ AP 1: What physical and perceptual limitations to access to subsistence resources by local residents are caused by oil/gas activities?

Description:

Access to subsistence resources is determined by both the changes in resource distribution and the ability of subsistence users to access resource distribution areas. While development of oil/gas activities may change the distribution of species, spreading them farther or closer to subsistence users, increased incomes due to these developments may increase the ability of subsistence users to access the changed distribution areas. As such, the physical and perceptual limitations to access are dynamic and depend on several factors.

Process Model:



Methods:

All source datasets will be clipped to the study area and thus will include only features that are within the NOS REA boundary. Physical structures that may be potential barriers for access can easily be identified through information location of infrastructure such as gravel pads and roads. These have definite identifiable physical impacts on distribution of various species. Where documented attributes are available, this will be addressed as part of the core analysis assessing the impacts of each change agent on each conservation element. Where such information is unavailable, the landscape condition model (LCM) will identify the parts of landscape with lower likelihood to support various species. Perceptual limitations can vary by each user and such information is typically embedded in reports on hunting and fishing practices of different populations. It can be an extensive process to review the reports and extract this information. Where possible, such a search will be limited to literature on species occurring on land and in-land water bodies.

Challenges:

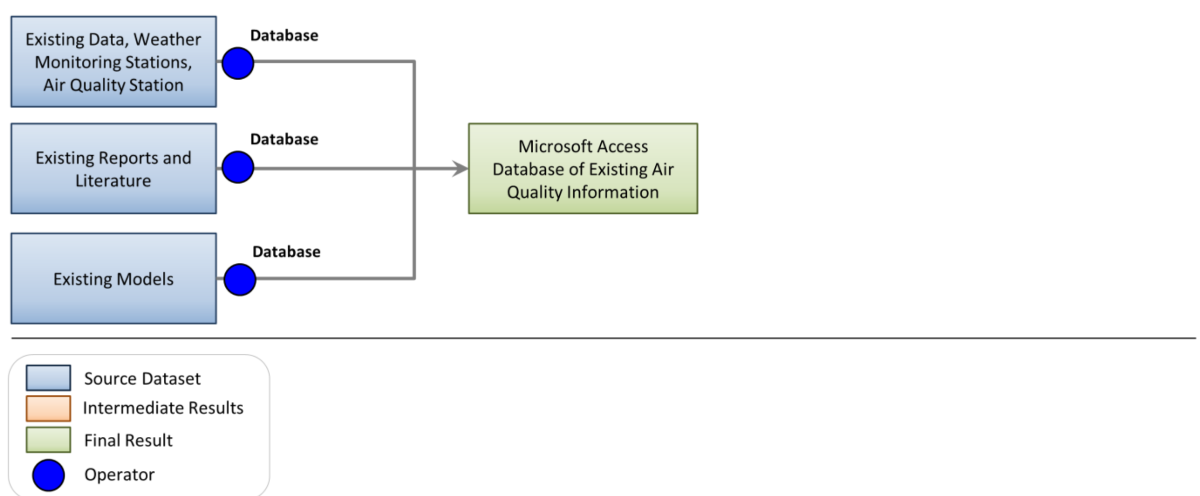
Reports that may have information on perceptual limitations will be identified, but extracting this information to meaningfully answer this part of the question may be beyond the scope of this project. This cannot be determined until the extent of available information is known.

MQ AP 2: How are oil, gas, and mineral development on the North Slope impacting near- and far-field air quality, with particular emphasis on communities and "sensitive class 2" areas such as Arctic National Wildlife Refuge, Gates of the Arctic National Park, and Noatak National Preserve?

Description:

The BLM modeled air quality for the 2012 Integrated Activity Plan/Environmental Impact Statement (IAP/EIS) for NPRA based on meteorological data and emissions scenarios.[3] Although the input data was marginal and the outputs had high uncertainty, the results indicated that oilfield development could fail to meet both nearby Clean Air Act (CAA) ambient air standards and air quality related value standards in National Parks and National Wildlife Refuges hundreds of miles away. MQ AP 2 requires a compilation of existing data, information, and models related to air quality on the North Slope that can serve as input data for or otherwise inform future modelling efforts.

Process Model:



Methods:

A basic conceptual model and accompanying description of key variables influencing air quality on the North Slope, including atmospheric chemistry, pollutant transport, and development, will be developed by the UA Team and reviewed by the BLM Division of Resource Services (DRS). A catalog of existing air quality data related to the North Slope will be compiled in a Microsoft Access database. By an agreement with BLM, no spatial or mathematical modeling will be conducted for this MQ.

Challenges:

Air quality data within the North Slope is sparse, largely because of the high cost and difficult logistics of monitoring air quality in arctic Alaska. Permanent air quality monitoring sites within or near the study area are currently few: an active monitoring station exists at Bettles (originally located at Ambler) just south of the study area boundary and a new BLM monitoring station is planned at Inigok. Additional air quality data have been collected by private industries, primarily in oil fields. Existing models vary in their

[3] BLM 2012

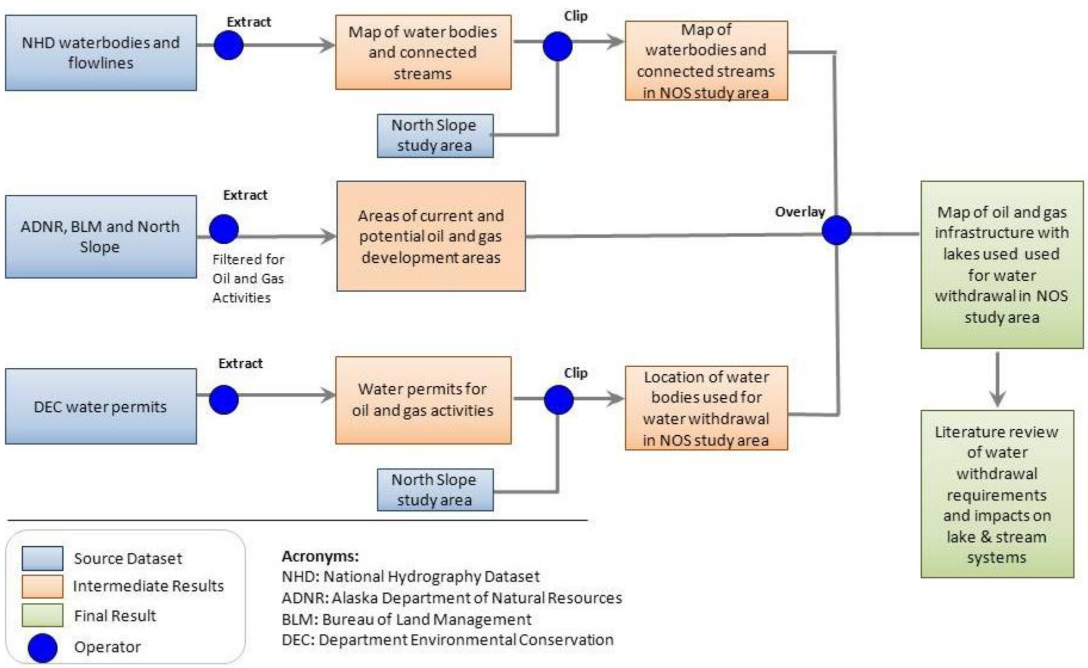
purpose, scale, resolution, input and computing requirements, and cost. Not all existing meteorological and emissions datasets include the necessary parameters required of inputs to various existing models.

MQ AC 1: How does water withdrawal from lakes for oil and gas activities (year-round industrial and domestic use and winter operations) affect lake water quantity and water quality, outflow/stream connectivity, and down-basin habitat?

Description:

Water withdrawal for oil and gas activities affects several attributes of water bodies. This question is focused on lakes and connected streams. The quantity of water withdrawal depends on the type of use. The Alaska Department of Environmental Conservation issues water use permits for all industrial activities. These uses can be identified and classified by season.

Process Model:



Methods:

Lakes and connected streams within the NOS REA study area will be extracted from the NHD. Areas of oil and gas development will be obtained from ADNR, the North Slope Borough, and BLM. Information on lakes currently used for water withdrawal will be obtained from DEC water permits. These source datasets will be intersected to provide information on the spatial extent of the potential impacts that water withdrawal from oil and gas activities could have on lake habitats within the NOS REA study area. This map will highlight lakes already used for water withdrawal and lakes that are within development areas that could potentially be used for water withdrawal. Lastly, a literature review of water withdrawal requirements and the measurable impacts on both quality and quantity to lake and stream systems will be conducted.

Challenges:

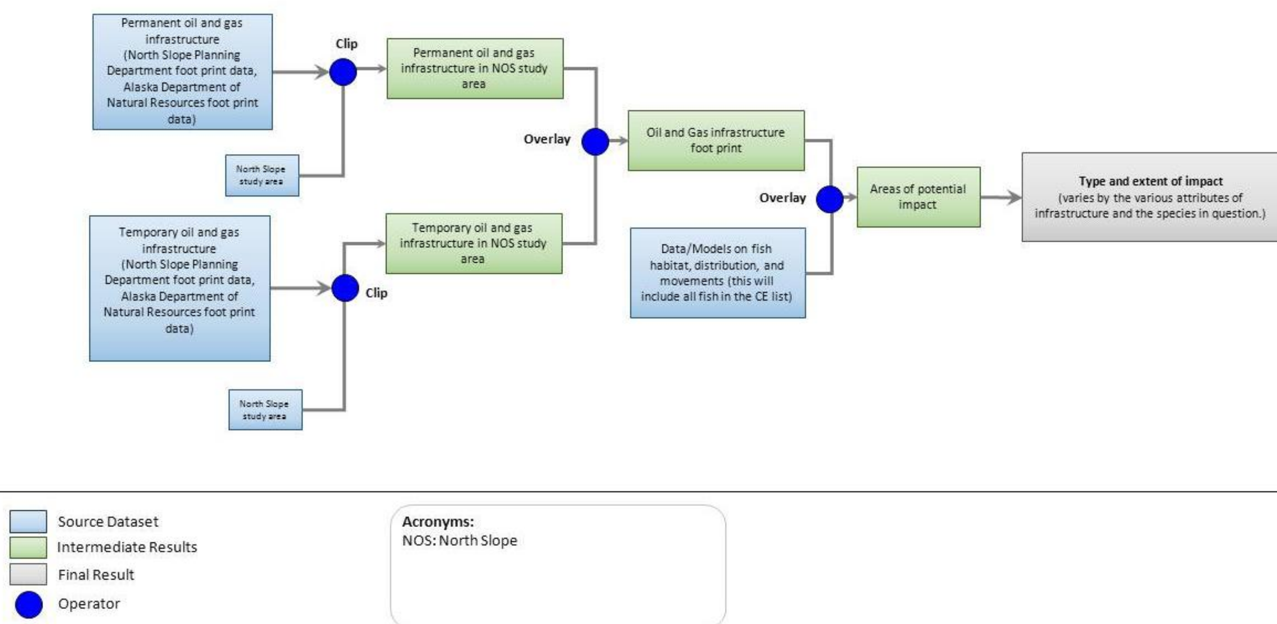
Water withdrawal for non-industrial uses (including domestic use) may not require permits, and thus may be difficult to identify and classify. The NOS REA lacks an aquatic habitat map necessary to define

Aquatic Coarse-Filter CEs by habitat. The best available data source for identifying aquatic habitats within the NOS REA study area is the NHD. However, the NHD is outdated and lacks the spatial accuracy and attribute information necessary to map aquatic habitats. Thus, the Aquatic Coarse-Filter CEs have been identified as a data gap and our ability to answer this MQ spatially will be limited. Data limitations on stream connectivity will further limit our analysis of outflow and stream connectivity as well as down-basin stream affects.

MQ AC 2: How does oil and gas infrastructure (e.g. roads, pads, pipeline), both permanent and temporary, affect fish habitat, fish distribution, and fish movements?

Description:
The impacts of oil and gas infrastructure on several species on the North Slope have been studied extensively. While most infrastructure for these activities in the region are expected to be temporary, the life span of these activities and some of the associated infrastructure can last several decades, with substantial impacts on many species including fish. MQ AC2 can include several species of fish, but will be limited to those identified in the CE list.

Process Model:



Methods:
Lakes and connected streams within the NOS REA study area will be extracted from the NHD in answering AC 1, as shown in the process model for that MQ. Areas of oil and gas development will be obtained from ADNR and the North Slope Borough. CE fish distribution maps will be intersected with oil and gas infrastructure data layers and the lakes and connected streams distribution maps. A literature review will be conducted to assess oil and gas specific infrastructure effects on fish habitats distributions and movements within the NOS REA study area.

Challenges:
The degree to which fish occurrence and distribution can be approximated will depend on available data, which in many cases may be sparse. Although the oil and gas industry has conducted extensive fish studies within the NPRA, in most cases, these data are not made publicly available.

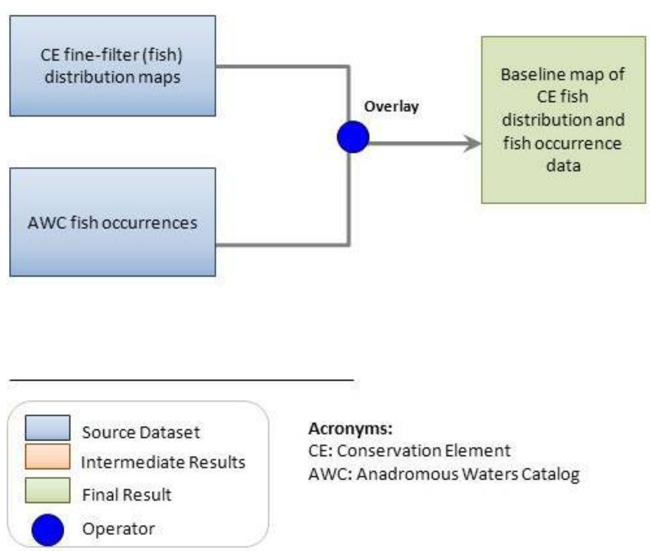
The NOS REA lacks an aquatic habitat map necessary to define fish habitat. The best available data source for identifying aquatic habitats within the NOS REA study area is the NHD. However, the NHD is outdated and lacks the spatial accuracy and attributes information necessary to map aquatic habitats. Thus, our ability to answer spatially how oil and gas infrastructure affects fish habitat will be limited.

MQ AF 1: What are the baseline characteristics and trends in fish habitat (lakes and streams), fish distribution, and fish movements?

Description:

This question requires that we obtain and assemble historic and current information for trends in fish habitats from studies that focus on monitoring and tracking changes in these habitats over time. Similarly, baseline fish distribution and movement data would include presence/absence data, telemetry data, and/or data from mark-recapture studies. To our knowledge, these data sets do not exist for fish habitats in the NOS study area, and we are considering them a **data gap**. Few studies had focused on trend and movement data for fish species, but many of these surveys were conducted by private entities and are proprietary in nature. However, using distribution maps that we develop for the Aquatic fine-filter CEs and fish presence data obtained from the Anadromous Waters Catalog (AWC), we will develop a map that will serve as baseline fish distribution data for the five aquatic fine-filer CEs for the NOS REA study area.

Process Model:



Methods:

Distribution maps of the Aquatic fine-filter CEs (broad whitefish, burbot, arctic grayling, Dolly Varden, and chum salmon) and fish presence data obtained from the AWC will be used to develop a baseline map of fish distribution and occurrence data for species within the NOS REA study area.

Challenges:

Baseline data on trends in fish habitats are considered a **data gap,** as we are not aware of any studies that have looked at trends in fish habitats within the NOS study area. Although fish movement studies have been conducted within portions of the NPRA, these data are not publicly available and are therefore considered a **data gap** for the NOS REA. We will also map point (occurrence) data for fish species covered by the AWC within the NOS REA study area.

MQ AF 2: What are the measurable and perceived impacts of development on subsistence harvest of fish?

MQ TF 3: What are the measurable and perceived impacts of development on subsistence harvest of caribou?

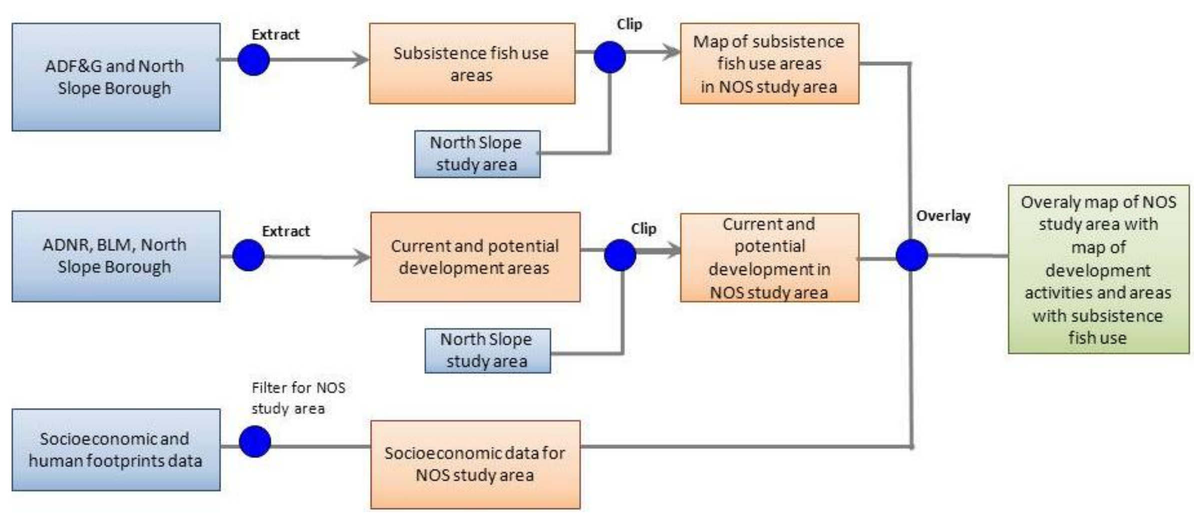
MQ AF 2 and MQ TF 3 are similar questions and the methodology used to answer these questions will be similar. In the description and process model below, fish subsistence use areas and harvest data can be replaced with caribou subsistence use areas and harvest data.

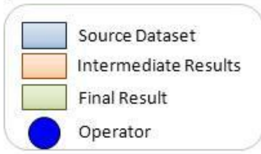
Description:

Development can be conceived as physical, social, and economic. Impacts of each type of development on subsistence harvest can be difficult to differentiate. The impacts can be either positive or negative. For example, development can lead to higher human population, higher incomes enabling people to afford subsistence gear and better storage facilities, expanded infrastructure increasing the subsistence use areas, all having a positive (tending to increase harvest) impact. On the other hand, development can also lead to changing cultural preferences (being indoors instead of out fishing), higher opportunity costs (the certain loss of income from regular employment for the time spent on subsistence activities with uncertain gains), increased ability to participate in cash economy, and potentially overharvesting due to better access to subsistence resources. This question can include several species of fish, but will be limited to those identified in the CE list.

Perceived impacts will be identified through a literature review of reports containing descriptions of changes in life on the North Slope as a result of oil and gas development in the region. We will explore documentation from Environmental Impact Statements, various studies of the region's economy, social and economic status of the population, etc. In addition, several peer-reviewed publications reporting on similar changes will be reviewed.

Process Model:





Acronyms:
ADF&G: Alaska Department of Fish and Game
ADNR: Alaska Department of Natural Resources
BLM: Bureau of Land Management

Methods:
Measureable impacts will be addressed by developing a map of current subsistence use fish areas (based on ADF&G and North Slope Borough data). These data layers will be overlaid with ADNR and BLM current and potential development data layers within the NOS REA study area. The product of these overlays will be a map of areas within the NOS REA study area that have development activities. The resulting spatial analysis will yield measureable spatial attributes of impacts on harvest of fish or caribou. Spatial results will be reported at 5th level HUC, unless the data does not allow. In addition, the economic model, if data is available to meaningfully run it, will yield other measurable non-spatial attributes such as opportunity costs that impact harvest levels of fish and caribou.

Perceived impacts will be identified through a literature review of previous reports from subsistence analysis workshop ethnographic studies and Traditional Ecological Knowledge (TEK). A literature review will aid in assessing the perceived impacts from development on changes in subsistence use (e.g., more use with more roads/access, less use due to negative impacts on fish populations, etc.).

Challenges:
Measuring the impact of development on subsistence harvest is difficult since harvest data are point in time estimates, even if collected periodically over long periods of time. Harvest depends on the demand for and supply of subsistence resources. Existing literature will be reviewed to identify appropriate indicators of supply and demand, and where available, data on these indicators will be used to build an economic model of the impacts of development on subsistence harvest. To our knowledge, this has not been done before.

Quantifying the perceived impacts of development on subsistence harvest of fish is inherently difficult. Socioeconomic data over time is generally scarce in Alaska. Large amounts of data over time are needed to test a model like the one discussed above.

MQ AT 1: What parameters can help measure impacts from anthropogenic activities independently of natural cycles and vice versa?

MQ AT 2: What potential impacts will oil/gas exploration and development have on CE habitat?

Both the above questions are related in their scope and interpretation. MQ AT 1 is more comprehensive while MQ AT 2 deals with specific anthropogenic activities on each CE habitat.

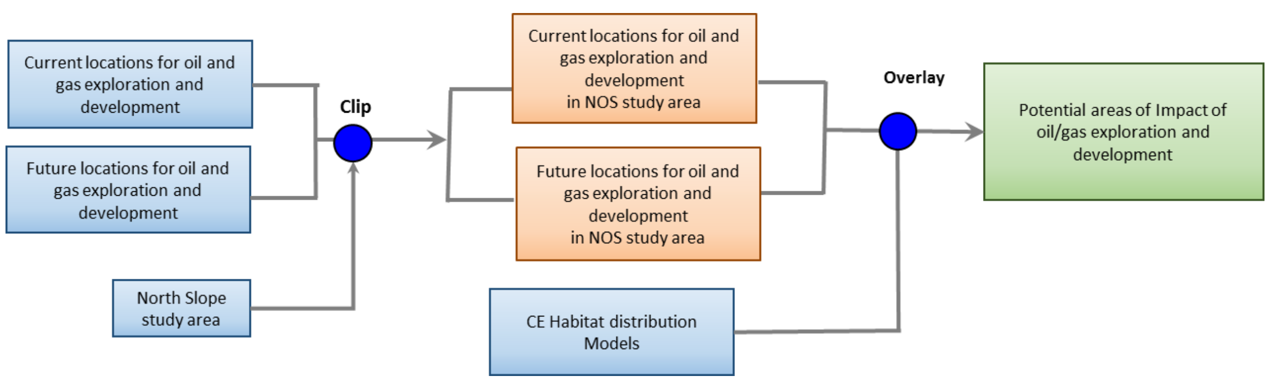
Description

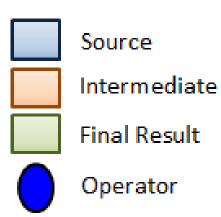
'Parameters' are interpreted to mean 'indicators.' This question seeks to identify those parameters that can help measure impacts of anthropogenic and natural causes, independent of each other. This is a research question that cannot be answered using existing research or available data.

Several studies have been conducted in the region that identify the impacts of anthropogenic activities on wildlife species and other ecological processes, including impacts on nest survival of tundra birds on the arctic coastal plain,[4] arctic fox,[5] and caribou.[6] Although some of these studies have been able to isolate the impacts of various stressors, to our knowledge nothing has yet been standardized.

As part of the core analysis, we will be identifying attributes and indicators to help to define the relationships between conservation elements (CEs) and change agents (CAs), and, where possible, thresholds associated with these relationships (see Chapter 3; Attributes and Indicators). If we are able to identify specific thresholds (data) associated with anthropogenic or natural cycles and how they impact species or habitats, then we can potentially model these relationships.

Process Model:





Acronyms:
NOS: North Slope
CE: Conservation Elements

4 Liebezeit et al. 2009
5 Ballard et al. 2000
6 Cronin et al. 1998, Joly et al. 2006

Parameters of impact differ by the type of anthropogenic activity and by the species examined. It may not be possible to identify a universal set of parameters for all species, but some parameters may be common among certain types of anthropogenic activities vis-a-vis certain species. A more promising and useful task may be to identify effective methods used to assess anthropogenic impacts. A preliminary review of the literature indicates that considerable investment is required to design and implement monitoring studies which need to span several years or decades in order to adequately isolate and assess the impact of anthropogenic activities independent of natural cycles. Literature will be reviewed to identify methods used to assess these impacts, and recognized impacts of individual anthropogenic activities on each CE will be documented.

Methods:

Methods designed to identify parameters to measure impacts on ecosystems due to various stressors have evolved over the last several decades. These range from simplistic methods that rely on correlation between changes in mean abundance, size, or diversity of species and human activity, to more complex temporal and spatial sampling techniques that can detect not only changes in averages but also changes in natural ecological events in specific species. Despite the growth in complexity, serious flaws remain in almost all available methods. Additionally, data required to implement these methods can require extensive monitoring programs spanning several decades and thus, are very expensive.[7] These sampling designs include before/after contrasts at a single site, repeated before/after sampling at a single site, before/after and control/impact sites, and repeated before/after sampling at control and impacted sites.

MQ AT 2 focuses on one specific anthropogenic activity that is a composite of many smaller activities. Oil and gas exploration and development includes several activities such as gravel pads, access roads, associated pipelines, transportation infrastructure including trails, vehicular traffic, dust accumulation, material sites, gravel mines, sewage lagoons, reserve pits, small and large pollutant spills, seismic trails and snow pads. Each of these exist in the current and future exploration maps. Each activity may have differential impact on any particular CE habitat.

Challenges

Analysis for MQ AT 1 will be limited to the identified anthropogenic activities in the CA list and the species identified in the CE list. As mentioned above, identifying parameters to assess the impacts of anthropogenic activities independent of natural cycles is a research question that is beyond the scope of the REA, except in the context of what we can achieve through the assessment of attributes and indicators.

[7] Underwood 1991

MQ AT 3: What additional contaminants baseline data are needed for fish, birds, marine and terrestrial species, particularly those that affect the health and safety of subsistence foods?

Description:

This question seeks to document the gaps in baseline data on contaminants that affect health and safety of subsistence foods. However, gaps can be identified only if we know the current available data. Therefore, current available baseline data on contaminants, as well as possible pathways by which contaminants reach the animals and plants in question (i.e. edible), will be identified and thus gaps will be noted.

Methods:

The Alaska Department of Environmental Conservation maintains a list of contaminated sites with some detail on the contaminant and the extent of contamination. For example, mercury contamination is available in more detail than others. Several studies were conducted in the last several decades attempting to track the presence or concentrations of various contaminants such as lead,[8] cadmium, mercury, and selenium.[9]

Common contaminants in the region will be identified through a review of peer-reviewed and gray literature, as will the assessment of pathways of contamination. The availability of data will be assessed for its extent and quality.

Challenges:

There may be undocumented contaminants and assessing such data needs is impossible.

[8] Grand et al. 1998
[9] Wayland et al. 2001, Franson et al. 2009

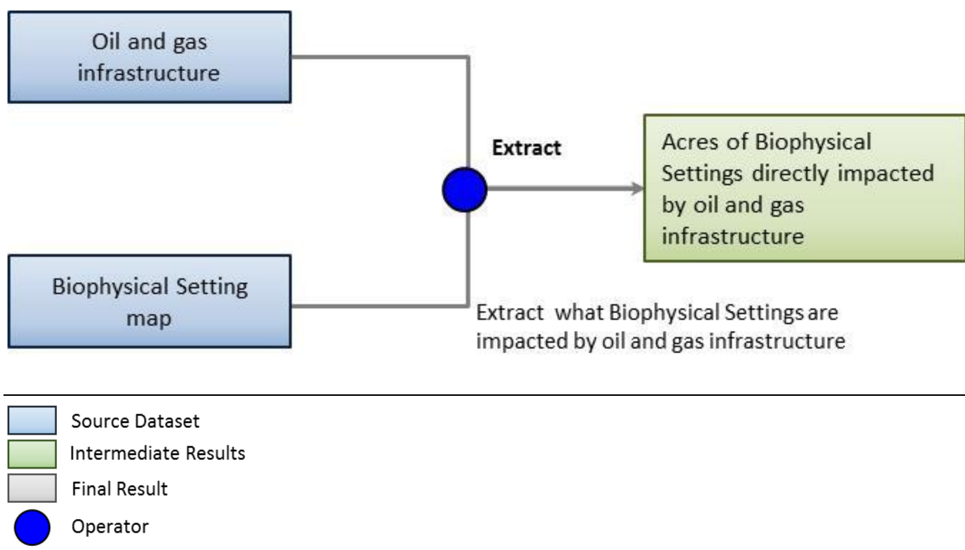
MQ TC 1: What are the impacts of oil/gas development (i.e. gravel pad and road construction; pipeline construction) on vegetation and hydrology? (Known impacts include burial, dust, saline runoff and altered soil moisture.)

Description:

We will treat this question as including only direct impacts from the oil and gas development (i.e. gravel pad and road construction; pipeline construction). Descriptions will include general impacts to Biophysical Settings, existing vegetation and surface hydrology. We will not address ground water hydrology, permafrost or thermokarst due to lack of data.

This question will be addressed primarily through a literature search. The only GIS processing will be an overlay of the oil and gas infrastructure shapefile with the Biophysical Setting dataset. Consequently the process model only includes this one step.

Process Model:



Methods:

For vegetation we will conduct a literature review and describe the known impacts of oil and gas development (i.e. gravel pad and road construction; pipeline construction) on vegetation. These will be general descriptions per impact. We will also address this question in GIS by overlaying the oil and gas infrastructure shapefile (one of our CA layers) with the Biophysical Setting map shapefile (one of our CE layers).

For surface hydrology we will conduct a literature review and describe the known impacts of the oil/gas development (i.e. gravel pad and road construction; pipeline construction) on surface hydrology. Again, these will be general descriptions per impact.

Challenges:

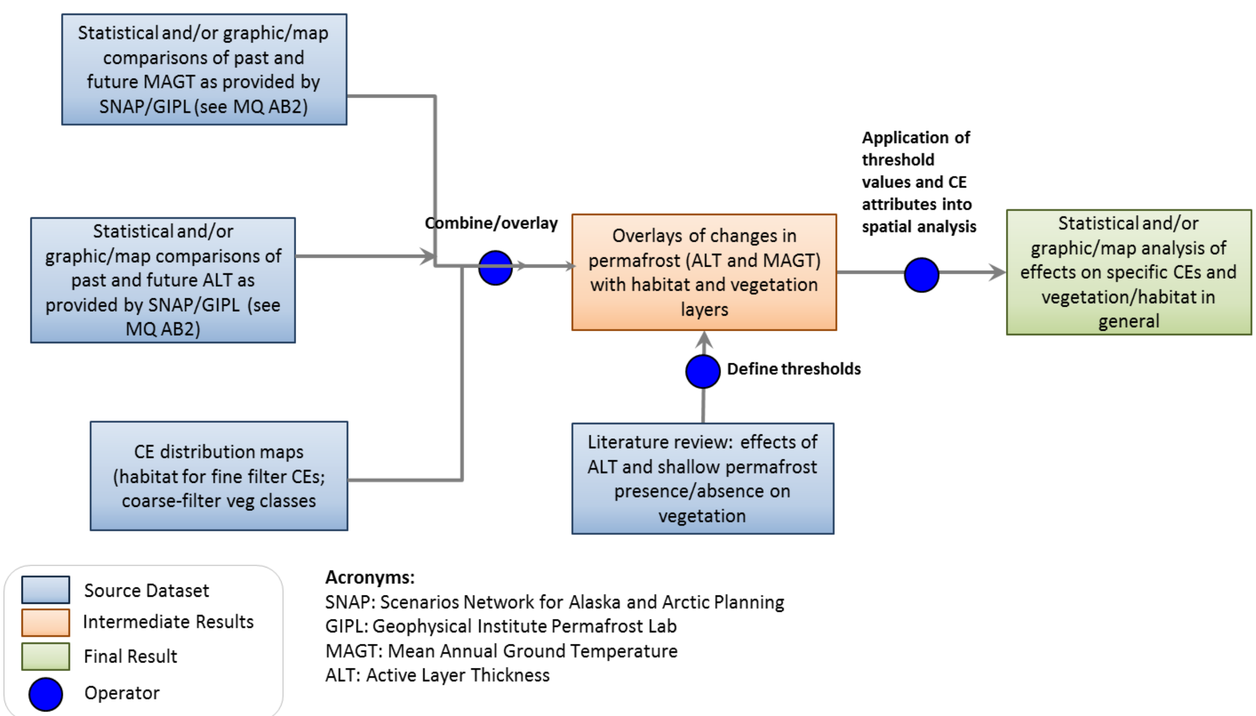
Many of the studies have been conducted by the oil and gas industry and it can be difficult obtaining this information due to their internal restrictions on data-access.

MQ TC 2: What are the changes in habitat and vegetation related to changing permafrost conditions, and what will these changes mean to wildlife and habitats?

Description:

Changing soil thermal dynamics play a key role in ecosystem function in Arctic Alaska. Even a small increase in active layer thickness (ALT) can allow new species to take hold, new drainage patterns to occur, and wetlands to appear or disappear. This question asks us to link projections of permafrost change and ecosystem components, with the final product being statistical or spatial analysis of effects on plant and animal species.

Process Model:



Methods:

As described above, the SNAP/GIPL model provides the best available data on past, present, and future ALT and mean annual ground temperature (MAGT). In order to link these projected changes to potential changes to habitat, we will perform an extensive literature review to explore what quantitative and qualitative information is available linking habitat location and quality to these variables. We will provide our best interpretation as to how vegetation will change at 25 and 50 years, and apply it to the Biophysical Setting (BpS) map. One result, for example, may be expansion of the Balsam poplar existing vegetation class into the Floodplain BpS. Another may be an increase in the Low shrub existing vegetation class into the Foothills Tussock Tundra BpS.

Challenges:

In addition to the uncertainty inherent to both the GIPL and SNAP models, uncertainty is likely to exist in the literature. While habitat quality is likely to vary across the REA, pinpointing direct and clear linkages to permafrost conditions may prove difficult, except in cases where studies have specifically examined transects – in either time or space – involving varying permafrost conditions. Such studies are unlikely to be available for all habitat types or all species of interest.

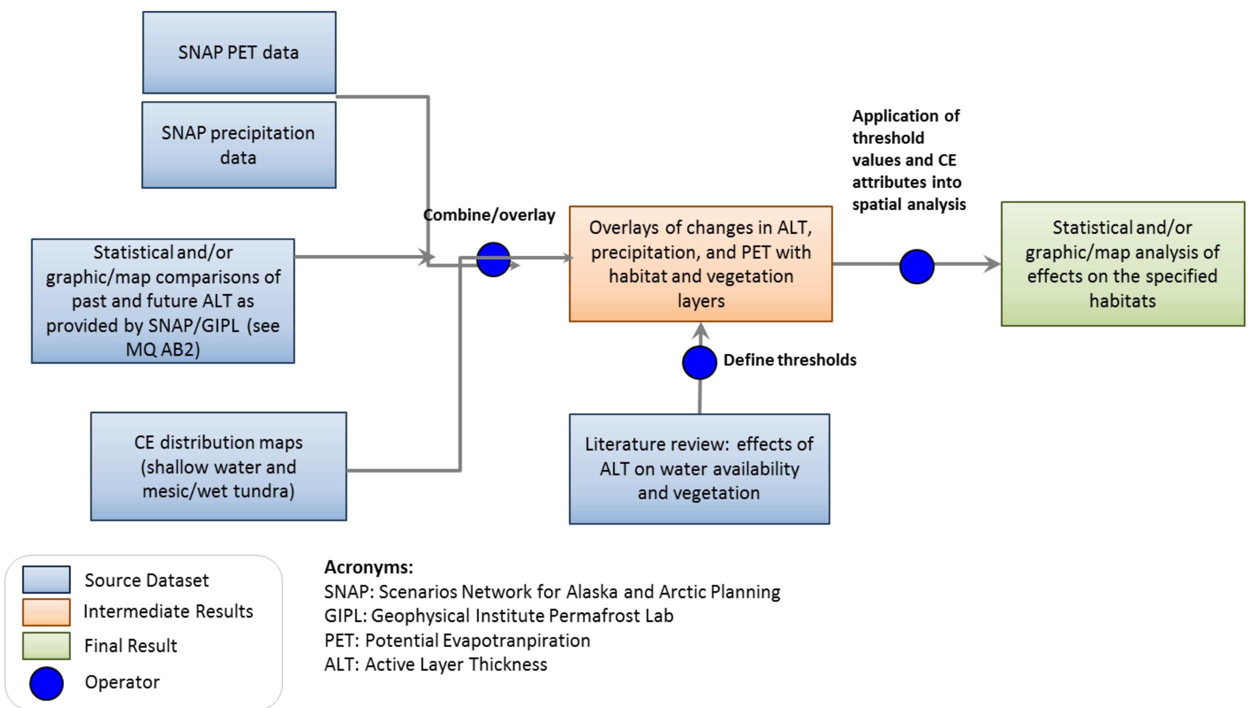
MQ TC 3: How will changes in precipitation, evapotranspiration, and active layer depth alter summer surface water availability in shallow-water and mesic/wet tundra habitats and how reliable are these projections?

Description:

As described above, changes in permafrost can alter hydrology at the landscape level, even if complete thaw does not occur. When coupled with potential changes in both evapotranspiration and precipitation, the future outlook becomes more complex. The answer to this question requires spatial analysis of how climate change may impact all of these variables, and what the effects will be in terms of water availability.

We will provide our best interpretation as to how summer surface water will change in shallow-water and mesic/wet tundra habitats at 25 and 50 years.

Process Model:



Methods:

SNAP/GIPL models of ALT have already been described. In addition, SNAP has data for both precipitation projections at monthly resolution, and projected evapotranspiration, based on projected changes in temperature. These inputs can be analyzed in conjunction with one another to provide a more complete view of water availability and hydrologic change.

Challenges:

As mentioned, changes in permafrost are likely to cause hydrologic changes, but this change can be exceedingly difficult to pinpoint spatially. One area may become drier while another becomes wetter. The precise timing of thaw and the micro-occurrence of thaw at scales finer than that allowed for by the

SNAP/GIPL model (1km) render this question hard to predict except at a broad scale. SNAP's model of evapotranspiration, while rigorous, is limited by the limited data available as an input – that is, monthly rather than daily or hourly projections of temperature, imperfect vegetation data, and imperfect data linking temperature, vegetation, and evapotranspiration rates.

MQ TC 4: What are the expected changes to habitat as a result of coastal erosion and coastal salinization?

Description:

The combined effects of rising sea level, declining sea ice, increasing summer ocean temperature, increasing storm power, and subsidence of coastal permafrost have had a dramatic effect on the arctic coastline of Alaska. Several studies have documented the loss of land area due to coastal bluff erosion and the impact to low-lying coastal vegetation from inundation and sedimentation. To answer this question we will compile existing information and conduct a literature review to summarize the expected changes to habitat.

Process Model:

Literature reviews do not involve logical processing steps and therefore do not require a process model.

Methods:

To answer this question we will review current studies and compile available information documenting coastal erosion and inundation. For study sites at which specific rates of erosion have been defined, we will be able to project the impact of coastal bluff erosion at 25 and 50 years. It will be more difficult, however, to project future rates of salinization of low-lying habitats. Inundation is a result of several interacting factors including storm surge and timing, presence of sea ice, and permafrost subsidence. We will compile information on the impact to coastal habitats from inundation and salinization, as well effects on the animal species that utilize them, but conducting a spatial analysis of the expected changes is beyond the scope of this assessment.

Challenges:

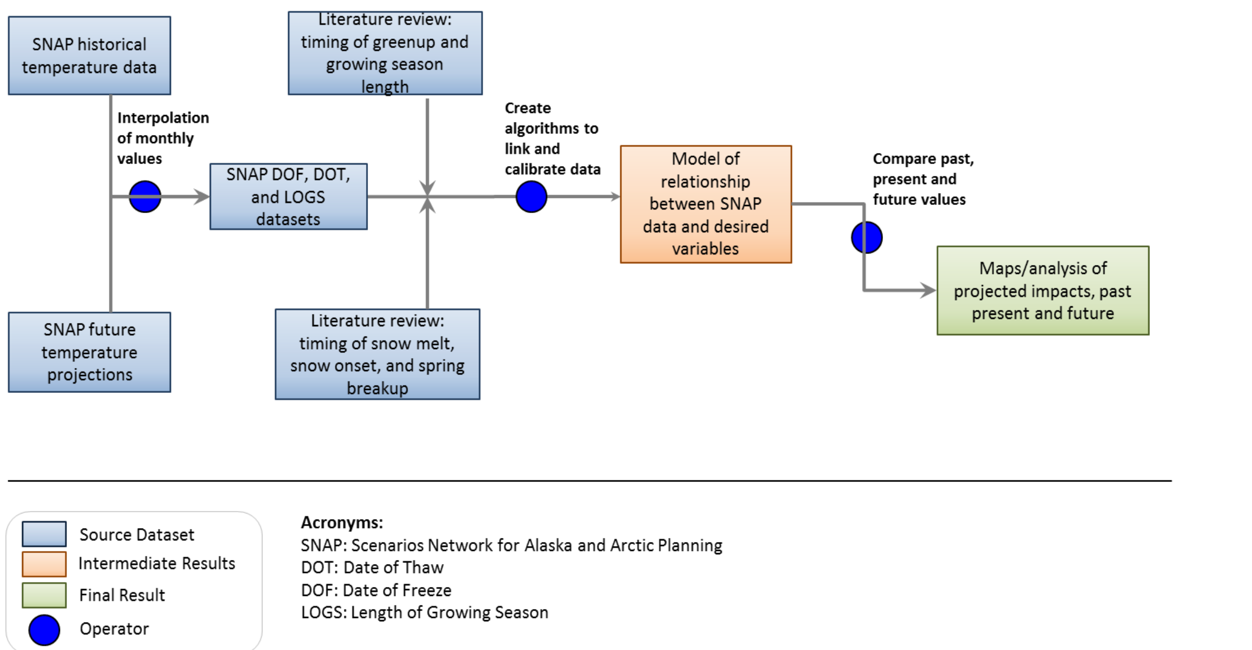
We explored contrasting an older coastline map with a new coastline map to empirically determine what habitats had been lost or gained due to coastal erosion. Unfortunately we could not use the older coastline map because its interpretation was inaccurate due to limitations in the technology available at the time it was created. Furthermore, interpreting habitat types from historic imagery is beyond the scope of this assessment.

MQ TC 5: How is climate change affecting the timing of snow melt and snow onset, spring breakup and green-up, and growing season length?

Description:

Summer season length and the timing of spring thaw and autumn freeze can greatly alter ecosystem dynamics, as well as the behavior of humans on the landscape. This question asks for specific information on shoulder season dynamics and length of growing season, to be presented spatially, as well as summarized at the scale of 5th-level HUCs.

Process Model:



Acronyms:
SNAP: Scenarios Network for Alaska and Arctic Planning
DOT: Date of Thaw
DOF: Date of Freeze
LOGS: Length of Growing Season

Methods:

SNAP datasets have already been derived to address this question. Most of these are derivatives of core SNAP monthly temperature data. In the case of thaw and freeze, these monthly data are interpolated to estimate the date upon which running mean temperatures are likely to cross the freezing point. Summer season length represents the number of days between these two dates. While snow onset and greenup are not likely to occur on these dates, literature review may shed light on the typical lag times that apply.

Challenges:

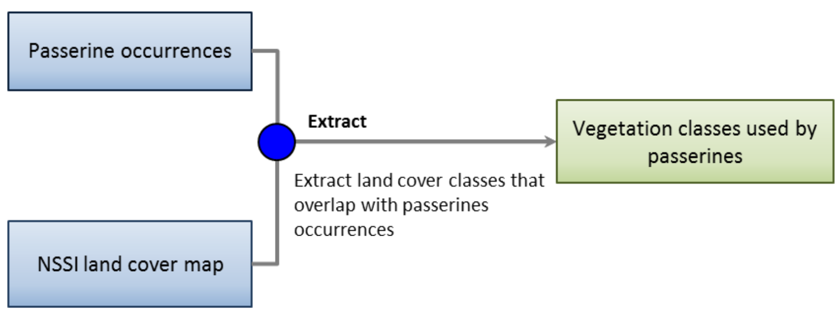
All climate projections are uncertain, and SNAP data must be considered as estimates of trend. Linking date of thaw and date of freeze to greenup and snowfall may prove challenging if additional variables – other than temperature – prove to be crucial.

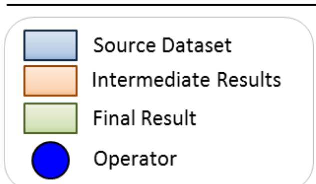
MQ TF 1: What are the baseline data for the species composition, number of individuals, vegetation type used, and change in number/species composition of landbirds and their habitat over time?

Description:

The avifauna of arctic Alaska is dominated numerically by waterfowl and shorebirds for which there are numerous long-term region-wide datasets available to assess distribution, trends and habitat use. This is not the case for landbirds, however, whose distributions are often more dispersed than waterbirds and shorebirds, and survey data tend to be more localized and disparate. This question requires that we obtain and assemble baseline information from historical and contemporaneous avian surveys to produce a spatial data layer that identifies the distribution and species composition of landbirds (passerines) across the NOS REA study area. We will then compare avian distribution information to existing maps of vegetative classes and identify those vegetation types that are used by passerines with the most frequency during the breeding season.

Process Model:





Acronyms:
NSSI: North Slope Science Initiative

Methods:

We will gather baseline data from numerous and disparate avian breeding surveys across the North Slope which will be summarized into a common format and then used to produce a spatial data layer depicting species distribution and species composition. To date, we have compiled breeding bird survey data from 41 unique surveys, spanning the time period 1948 to 2009. We will overlay the map of avian species distribution/composition with the existing NSSI land cover map for the North Slope to assess those vegetation types that are utilized by passerines with the most frequency during the breeding season.

Challenges:

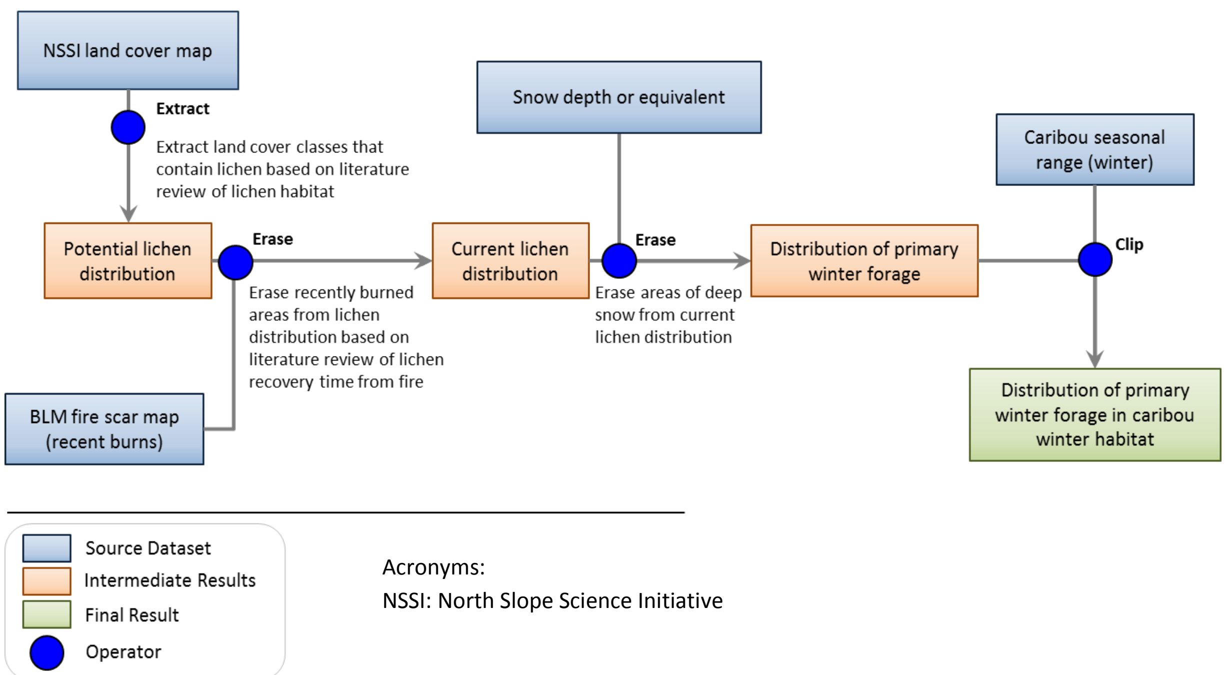
This question is extremely time intensive to answer and we feel that some components of the question are beyond the scope of the REA due to the resources it will take to accomplish. Because many of the surveys utilized differing survey techniques, occurred in different habitats, exhibit substantial temporal variability, and are of varying quality and quantity, we feel that attempting to calculate the number of individuals, relative abundance or density and changes in those numbers or composition over time is beyond the project scope. Furthermore, we are not doing any hind-casting with this project, and feel that assessing historical habitat changes over time is also beyond the project scope. We will, however, make inferences about anticipated changes in response to climate change to the dominant habitat types and the ramifications of those changes on the landbird species that utilize them. Furthermore, the Lapland longspur was selected as a fine-filter CE, with hopes that the core analyses (CE x CA overlays) applied to this species and the habitats it utilizes will also be applicable across multiple landbird taxa.

MQ TF 2: What are caribou preferences for vegetation communities? Where do these vegetation communities exist?

Description:

Caribou are the dominant medium-sized herbivore on the North Slope. Ranges of four major herds, the Central and Western Arctic, Porcupine and Teshekpuk, extend into the North Slope study area during some part of the year. Habitat preferences of the four herds are generally well understood, but the distribution of preferential forage is not. Answers to this question will provide a literature synthesis of seasonally preferred forages and will then attempt to map the distribution of preferred vegetation communities during those times of year when caribou are under the most stress, including winter and summer (calving and insect relief). We will then compare the mapped results of preferred vegetation communities to the known seasonal distribution of caribou, which will be mapped under MQ TF 4.

Process Model: Winter Vegetation Preferences



Acronyms:
NSSI: North Slope Science Initiative

Methods:

As winter approaches, caribou generally migrate south to winter ranges on the Seward Peninsula, Brooks Range, Brooks Foothills, Richardson Mountains, and Ogilvie Mountains, although some caribou of the Teshekpuk Lake Herd remain on the coastal plain in the winter. Lichens are important forage for caribou that can influence population dynamics through effects on body condition, calf recruitment and survival.[10]

To map the distribution of lichen, we will extract all the landcover classes from the NSSI vegetation map

[10] Joly et al. 2010

that contain lichen. Based on literature review and areal extent of lichen distribution, we will assign a forage quality rank (good, moderate, low) to the vegetation types that contain lichen to produce a “potential lichen distribution” map. We will also consider the role that fire plays in destroying ground dwelling lichens, which can take several decades to regenerate to pre-burn levels. We will conduct a literature review to understand lichen recovery rates from fire for the different vegetation types. We will then apply the BLM fire scar map to the potential lichen distribution to determine what recently burned areas no longer support lichen. This will become the “current lichen distribution” layer.

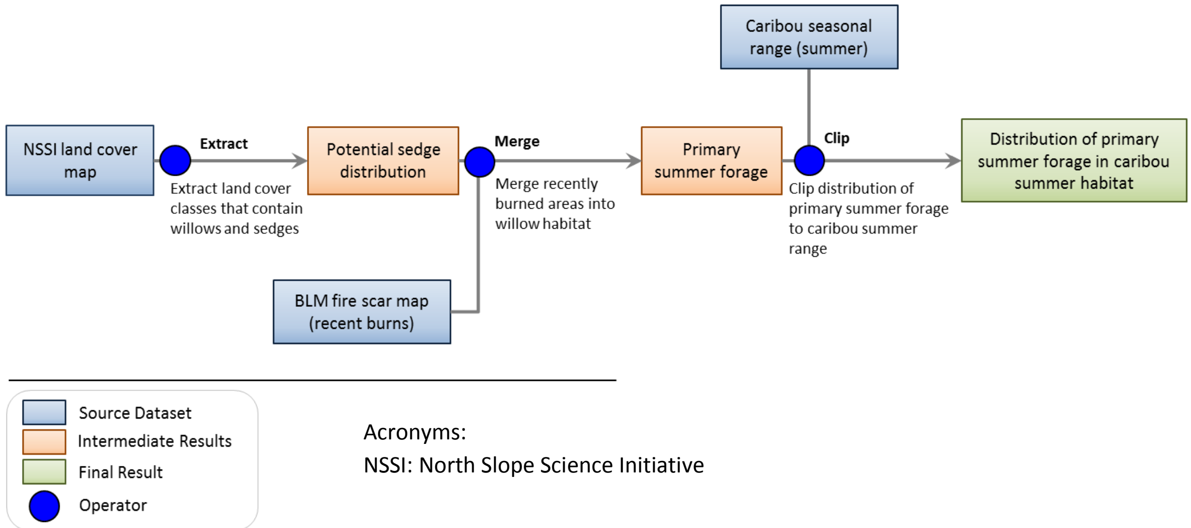
The current lichen distribution layer could potentially be the final answer to the question. However, we also feel it is important to consider snow characteristics in this assessment, as deep or crusted snow can reduce foraging efficiency for caribou. In order to further refine the model, we are exploring options to obtain a snow depth layer, or an appropriate surrogate for snow depth, for the North Slope. In the process model above, we make reference to a snow depth layer, but are not specific about the data source. Recently, we have been informed that Glenn Liston et al. from Colorado State are developing the SnowData dataset for the North Slope, which will include snow depth and snow water equivalent spatial data layers.[11] If available within the timeframe of this REA, we will overlay snow depth with the current lichen distribution map to further refine availability of lichen during winter. If not available, snow depth will be flagged as a data gap. Lastly, we will overlay (clip) the current known winter distribution of caribou (from MQ TF 4) with the lichen distribution map to assess how well the predicted lichen distribution map aligns with known winter distribution of caribou. All data processing will be done in ArcGIS utilizing existing datasets.

Challenges:

Lichen availability is not widely mapped the NSSI map. Not all mapped lichen is forage lichen. Being able to tease the different types of lichen apart may be problematic. Timing of availability of snow depth or snow hardness data layers (SnowData) may not coincide with REA deadlines. The final mapped product does not consider the effects of sustained grazing by the caribou themselves on lichen habitats, which also reduces forage availability. This effect, however, will be discussed during the final report write-up.

[11] Liston 2012

Process Model: Summer Vegetation Preferences



Acronyms:
NSSI: North Slope Science Initiative

Methods:

Caribou of all four herds exhibit similar timing of life events. Migrations toward calving grounds on the Beaufort Coastal Plain generally occur in April and May, and calving peaks around the first week in June. From late June to mid-August, caribou often form large aggregations and harassment from mosquitoes and oestrid flies are the primary determinants of caribou movements. Summer forages include willow leaves, sedges, flowering plants, and mushrooms, with a preference for sedge-grass meadows and *Carex aquatilis*.

We will conduct a literature review to identify those vegetation communities (land cover classes) preferred by caribou during the summer (calving and insect relief) specific to the North Slope. We will then extract these land cover classes from the NSSI landcover map to produce a "potential sedge distribution layer." We will also conduct a literature review to understand recovery rates from fire for different vegetation types identified as preferred forage. We will then apply the BLM fire scar map to the potential sedge distribution to determine what (if any) recently burned areas no longer support summer forages. This will become the "primary summer forage" layer. Lastly, we will overlay (clip) the caribou summer seasonal range map (combined calving and insect relief ranges from MQ TF 4) with the primary summer forage layer to assess how well the predicted summer forage map aligns with the known summer distribution of caribou. All data processing will be done in ArcGIS utilizing existing datasets.

Challenges:

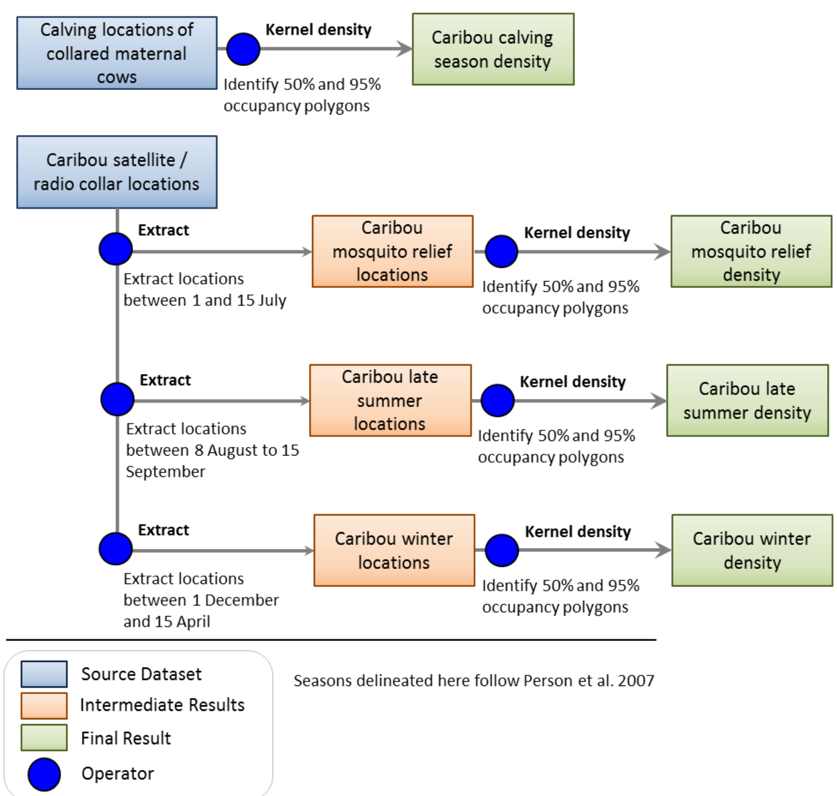
This is a very simplistic approach to a complicated question. Wilson et al. (2012) developed models that looked at summer resource selection and identification of important habitat for the Teshekpuk herd using the variables: vegetation type, elevation, distance to coast, and terrain ruggedness, which considered changes in both temporal and spatial scale. This type of analysis, however, is well beyond the scope of the REA. Simply put, we will provide baseline information derived through deductive techniques using existing datasets to provide managers with the current state of knowledge regarding habitats that are preferred by caribou based on literature review and expert opinion.

MQ TF 4. What are caribou seasonal distribution and movement patterns and how are they related to season and weather?

Description:

This question considers the seasonal distribution and movements of the four major caribou herds whose ranges extend into the study area: the Central and Western Arctic Herds, the Porcupine Herd and the Teshekpuk Herd, and how these movements are correlated with season and weather. **Seasonal distribution** of the four herds will be assessed during the calving season, when herds move to mosquito relief areas, late summer locations, and winter distribution. **Movement patterns** will be assessed to coincide with spring migration to calving grounds and fall migration to winter ranges.

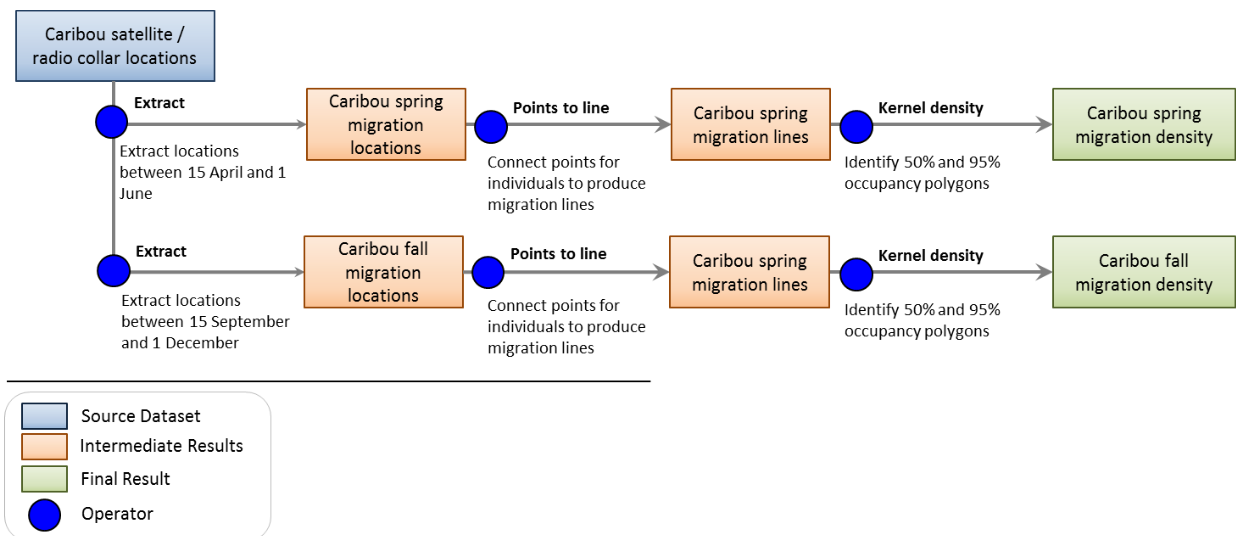
Process Model: Seasonal Distribution



Methods:

We are working with the Alaska Department of Fish and Game (ADF&G) through a data sharing agreement to obtain caribou radio-collar data that can be used to delineate the seasonal distribution of the four caribou herds across the North Slope. In the process model above we have outlined the spatial analysis that will be conducted on the radio collar-data to derive kernel density estimates of distribution. It is important to note that all spatial analysis of radio-collar data will be conducted by ADF&G biologists. Historically, this type of analysis has involved extracting radio-collar data points for the temporal period of interest[12] and then ranges for that time period are estimated using a kernel density estimation technique with range boundaries identified at the 50% (core) and 95% (peripheral) isopleths. Alternative methodologies to delineate core and peripheral seasonal ranges are also being explored by ADF&G for this analysis, including movement-based kernel density estimation (MKDE) and biased random brownian bridge (BRB) estimation techniques.[13] The final product that will be delivered by ADF&G for this assessment will be seasonal range (density) maps, such as those highlighted above in the green boxes: calving, mosquito (insect) relief, and winter. Here we have included "late summer density" as an final product, but it is unlcear at this time if data are sufficient to produce range maps for this time period. The effects of season and weather on caribou seasonal distribution will be assessed through literature review and are part of the REA core analysis and are described in detail in Chapter 3: Conservation Elements.

Process Model: Movement Patterns and Migration



Methods:

Similar to the methods for seasonal distribution described above, analysis of radio-collar data will be be used to delineate the seasonal migration of the four caribou herds between summer and winter ranges (spring and fall migration). Migration is loosely defined here as the seasonal movement between discrete areas not used by the herd at other times of the year. Analysis of radio-collar data will be performed by ADF&G biologists, under a current data sharing agreement for the NOS REA. We provide the basic framework for the spatial analysis process above, but the data that will be delivered by ADF&G for this assessment will be summarized movement patterns for numerous animals in the form of line density polygons, such as those highlighted above in the green boxes: spring and fall migration density. The effects of season and weather on caribou seasonal movements will be assessed through literature review and are part of the REA core analysis and are described in detail in Chapter 3: Conservation Elements.

[12] Seasons indicated in process models follow Person et al. 2007
[13] Benhamou 2011

Challenges:

Timing of both seasonal distribution and movements may not be synchronous between the four major herds. Therefore, the generalized date ranges that are provided above to bin the radio-collar data may not be consistently applied to all herds. These dates will need to be agreed upon by ADF&G biologists before the preliminary analysis can proceed. To date, ADF&G does not have data for the Porcupine herd, due to a shared border and management of the herd with Canada. If data for the Porcupine herd are not available through ADF&G, we will attempt to obtain spatial data (or tabular data that we can digitize) to delineate seasonal ranges and movements from the Porcupine Caribou Herd Satellite Collar Project.

Chapter 2: Change Agents

Change agents (CAs) are those features or phenomena that have the potential to affect the size, condition, and landscape context of Conservation Elements (CEs). CAs include broad factors that have region-wide impacts such as wildfire, invasive species, climate change, and pollution, as well as localized impacts such as development, infrastructure, and extractive energy development. CAs can impact CEs at the point of occurrence as well as through offsite effects. CAs are also expected to act synergistically with other CAs to have increased or secondary effects. Even though they are listed separately, not all development CAs occur alone. For instance, energy development require other CAs, namely transportation and/or transmission infrastructure.

Climate Change

Climate change drives multiple types of change in the REA and is also part of feedback loops with other CAs (such as fire) and CEs (such as all Terrestrial Coarse-Filter CEs). Climate change will be assessed using downscaled global climate models from SNAP, with subsets of the available data selected based on the needs of the project. For more information on the data being used for climate change, as well as other projects in which these data have been used, see www.snap.uaf.edu.

Model Methods

SNAP projections focus on the five available Global Circulation Models (GCMs) that perform best in the far north.[14] Global Climate Models (GCM) are developed by various research organizations around the world. At various times, the United Nations Intergovernmental Panel on Climate Change (IPCC) calls upon these organizations to submit their latest modeling results in order to summarize and determine the current scientific consensus on global climate change. There have been 4 assessment reports from the IPCC: in 1990, 1995, 2001 and 2007. In support of the more recent reports, the Coupled Model Intercomparison Project (CMIP) was initiated. Currently SNAP has utilized the CMIP3 model outputs from the IPCC's Fourth Assessment Report (AR4).

SNAP obtains GCM outputs from the Lawrence Livermore National Laboratory Program for Climate Model Diagnosis and Intercomparison (PCMDI) data portal. PCMDI supports Coupled Model Intercomparison Project (CMIP) and is dedicated to improving methods and tools for the diagnosis and intercomparison of Global Climate Models that simulate global climate. SNAP utilizes the first ensemble model run and the historical 20c3m scenario as well as the projected B1, A1B, and A2 datasets for downscaling.

SNAP climate datasets have been downscaled to 771 meter resolution using PRISM (Parameter-elevation Regressions on Independent Slopes Model) methodology,[15] which takes into account slope, elevation, aspect, and distance to coastlines. This downscaling uses a historical baseline period of 1971-

[14] Walsh et al. 2008
[15] PRISM 2012

2000. This baseline will be carried over for use in the REA. SNAP's downscaling is performed using the Delta method.[16]

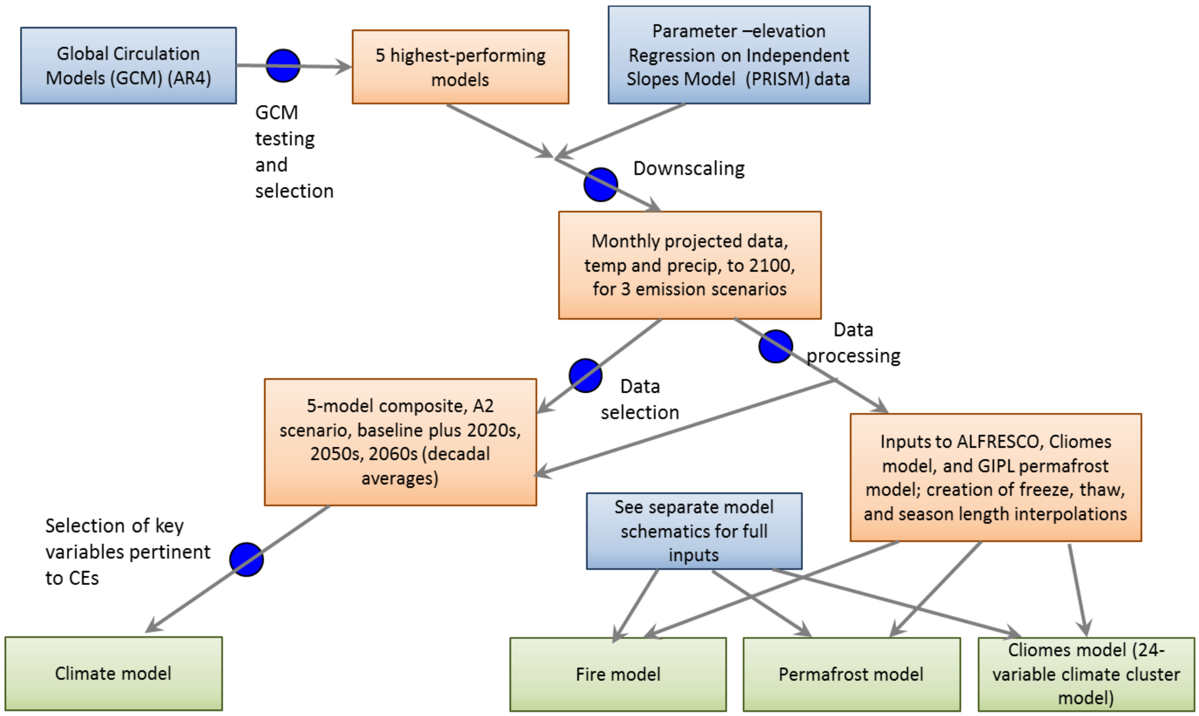
For this project, a composite (average) of the five GCMs selected and downscaled by SNAP will be used in order to minimize uncertainty due to model bias. This project will focus on the A2 scenario, representing a realistic view of future emissions. Decadal averages will be used, as opposed to data for single years, in order to reduce error due to the stochastic nature of GCM outputs, which mimic the true inter-annual variability of climate. Thus, the project will use climate data for the 2020s rather than just 2025, and the 2060s rather than the single year 2060.

SNAP climate outputs include temperature and precipitation data at monthly resolution. These data have also been analyzed to create derived climate datasets. Based on interpolation of running means, SNAP has created datasets estimating the date at which temperatures cross the freezing point in the spring and fall (termed "thaw date" and "freeze date" – although a direct correlation with ice on water bodies or in soils would not be expected). In addition, SNAP has used temperature data to create spatial estimates of potential evapotranspiration (PET) and monthly estimated snow fraction.

For the purposes of addressing MQs and effectively examining the relationship between climate and selected CEs, SNAP will provide both primary and derived climate data as described above. Ultimately, these datasets will be used in general discussion and analysis of climate change. A subset of these data will also be selected so as to best analyze the potential impacts of climate change on CEs, based on attributes and indicators determined from the literature, as described in this document. These datasets will be used in conjunction with maps of CE distribution as a basis for spatial analysis, creation of maps for the final report, and/or qualitative discussion.

[16] SNAP 2012

Process Model: Downscaled Climate Products



Climate model outputs can include GIS data, viewable maps, or tabular data. Climate data are also inputs to permafrost and fire models, described elsewhere in this report.

Limitations

Uncertainty is inherent in all climate projections; much of this uncertainty is addressed by using averages across multiple models and across decades, but all projections must still be understood in the context of SNAP's methodology. Climate data, while relatively fine-scale, do not always match the scale of phenomena that affect CEs. No direct data are available to link climate with water temperature, which limits the applicability of SNAP data to aquatic assessments. Moreover, available data do not always match, in scale or detail, the climate-related attributes and indicators most closely linked to particular fine or coarse CEs. Even when linkages between CEs and climate variables are relatively clear, in many cases, the literature does not provide precise information regarding threshold values.

Wildfire

Fire is both an integral ecosystem component and a key driver of change in Alaska. Warming climate is predicted to alter and shorten fire cycles, thereby changing vegetation patterns across the landscape. Increasingly, fire is also becoming a driver of change in tundra habitats, affecting species such as caribou that utilize these habitats.

Model Methods

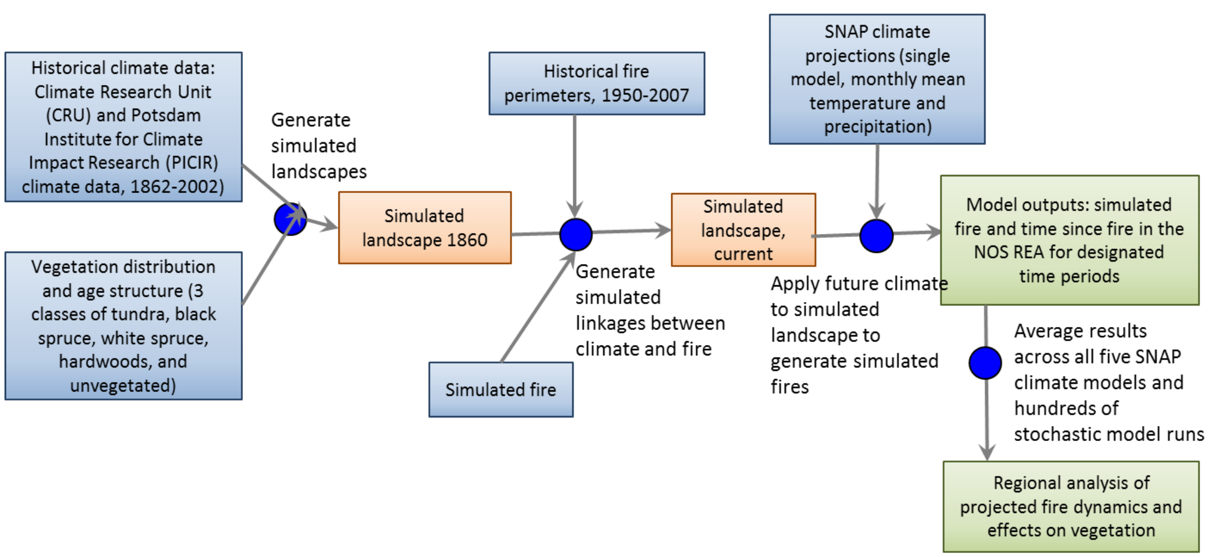
Modeling and analysis of these changes can shed light on multiple aspects of future ecosystem function, including human/landscape interactions. Fire will be modeled using ALFRESCO (Alaska Frame-based

EcoSystem Code) in the larger context of a projected future fire regime and its effects on major vegetation classes. Climate projections (as described above), past fire history, and current vegetation patterns will be used in part to model patterns of fire frequency across the landscape.

ALFRESCO simulates the responses of vegetation to transient climatic changes. The model assumptions reflect the hypothesis that fire regime and climate are the primary drivers of landscape-level changes in the distribution of vegetation in the circumpolar arctic/boreal zone. Furthermore, it assumes that vegetation composition and continuity serve as a major determinant of large, landscape-level fires. ALFRESCO operates on an annual time step, in a landscape composed of 1 × 1 km pixels. The model simulates a range of ecosystem types, including three distinct types of tundra, black spruce forest, white spruce forest, deciduous forest, and grassland-steppe. SNAP climate data, as described above, will be included among the ALFRESCO inputs.

The “distribution” of varying fire frequencies is intimately tied to vegetation, as well as climate, but also involves stochastic elements such as the exact location of lightning strikes and the variability of weather patterns at finer time-scales than are available to modelers. Thus, multiple model runs yield varying results. Therefore, fire distribution per se will not be modeled; rather the model will project its average frequency and extent across the landscape to ultimately model changes in vegetation patterns and distribution. Outputs will include landscape-wide estimates of percent cover by type and age, as well as projected average area burned per year across the target time periods (from the present to 2025 and from the present to 2060) and fire return intervals on a regional and sub-regional basis such as 3rd-level HUCs.

Process Model: ALFRESCO Fire Simulation Methodology



Limitations

No data are readily available to address the following fire-related variables, although some can be indirectly or qualitatively addressed:

- A wider range of cover types
- Fine-scale calibration of shifts in cover types post fire

These data gaps do not impede our ability to address fire as a CA. They do, however, somewhat affect the analysis of overlap between fire and CEs, in the sense that the Terrestrial Coarse-Filter CEs (Biophysical Settings) used in the REA do not precisely match the cover types used in ALFRESCO. However, it will still be possible to analyze, both quantitatively and qualitatively, the projected shifts in ALFRESCO vegetation classes.

Permafrost

Current permafrost conditions vary within the NOS Ecoregion. Although permafrost dominates most of the landscape, in some areas permafrost is discontinuous, particularly around water bodies, in coastal areas, and in the more southerly portions of the ecoregion. Coastal thaw has serious ramifications in terms of erosion, which can affect both human infrastructure and ecosystems. Permafrost on the North Slope of Alaska has warmed 2.2–3.9º C (4–7º F) over the last century.[17] Even in areas of continuous permafrost, active layer thickness varies on both a micro and macro level across the landscape. Indeed, the freezing and thawing of the active layer and the associated hydrologic dynamics are driving forces in shaping much of the topography of this region. Small differences in active layer thickness and associated patterns of drainage can yield large differences in drainage patterns, land cover, and vegetation. As such, soil thermal dynamics represent both a CA and a CE in Arctic Alaska (although we treat it as a CA in this analysis).

Model Methods

The main components of the permafrost model are represented in the general ecosystem conceptual model. Permafrost modeling will incorporate both SNAP climate projections and the Geophysical Institute Permafrost Lab (GIPL) permafrost model for Alaska, which relies on spatial data related to soil, vegetation, and climate. GIPL model outputs include mean annual ground temperature (MAGT) and active layer thickness (ALT), linked by appropriate algorithms.

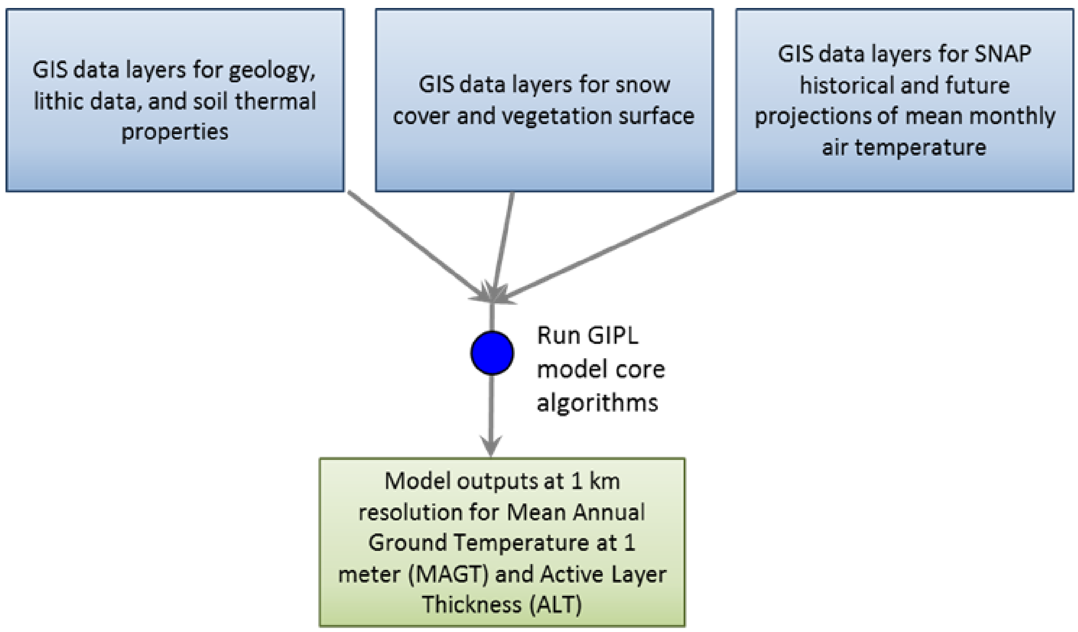
The Geophysical Institute Permafrost Laboratory (GIPL) model was developed specifically to predict the effect of changing climate on permafrost. The GIPL model is a quasi-transitional, spatially distributed equilibrium model for calculating the active layer thickness (the thin layer above permafrost that seasonally freezes and thaws) and mean annual ground temperature. Inputs include data from the Global Land Cover Characteristics Database Version 2 Surface vegetation thermal properties; National Atlas of the United States of America, 1985 Organic matter and vegetation thermal properties; and USGS, 1997 Surficial Geology Map of Alaska found on the Karlstrom (1964) statewide Alaska surficial geology map: soil thermal properties.

The GIPL permafrost model calculates permafrost extent, mean annual ground temperature, mean annual ground surface temperature, active layer thickness, snow warming effect, and thermal onset

[17] Goddard Space Flight Center 2014

from data inputs relating to the geologic and soil properties, effects of ground insulating snow and vegetation layers, and predicted changes in air temperature and annual precipitation. The primary outputs relevant to the NOS REA are the mean annual ground temperature (MAGT) at one meter depth, and the active layer thickness (ALT), which represents two different outputs: the depth of seasonal (summer) thaw, for areas with permafrost at one meter depth, and the maximum depth of seasonal (winter) freezing, for areas that are free of permafrost. Together, these properties delineate the presence and local extent of permafrost. The model is ground-truthed and validated using cores from around the state.[18]

Process Model: GIPL Permafrost Modeling Techniques.



Algorithms to determine MAGT and ALT are dependent on calculations of the insulating properties of varying ground cover and soil types, as well as on climate variables, and vary spatially across the landscape at a resolution of 1km. Outputs provide a general approximation of areas likely to undergo some degree of thaw and associated hydrologic changes. Model results will be presented in map and tabular form.

Limitations

The GIPL permafrost model provides a general and coarse approximation of permafrost conditions across the landscape. Despite the best available ground-truthing and validation of the GIPL model, and despite the use of the most reliable available climate projections from SNAP data, uncertainty is inherent in both models, and in the linked modeling of climate-induced permafrost change. Fine-scale changes in permafrost micro-conditions at a scale of meters rather than kilometers cannot be accurately predicted by the GIPL model. For example, the GIPL model cannot predict the formation of specific

[18] GIPL 2013

thermokarst features or the drainage of specific lakes from permafrost thaw. However, the predicted changes in permafrost at the landscape level indicate where such phenomena will be most likely.

Invasive Species

Invasive species are included in this REA and all other BLM REA's due to their widespread capacity to disrupt ecological processes and degrade biological resources. While much of Alaska, including the North Slope, has not witnessed dramatic impacts of invasive species in natural systems, they are increasing in abundance, distribution, and ecological and economic harm.[19] Non-native animal species are not known from this ecoregion; non-native plant species are known from within and adjacent to the North Slope ecoregion and we therefore focus on these species.

Model Methods

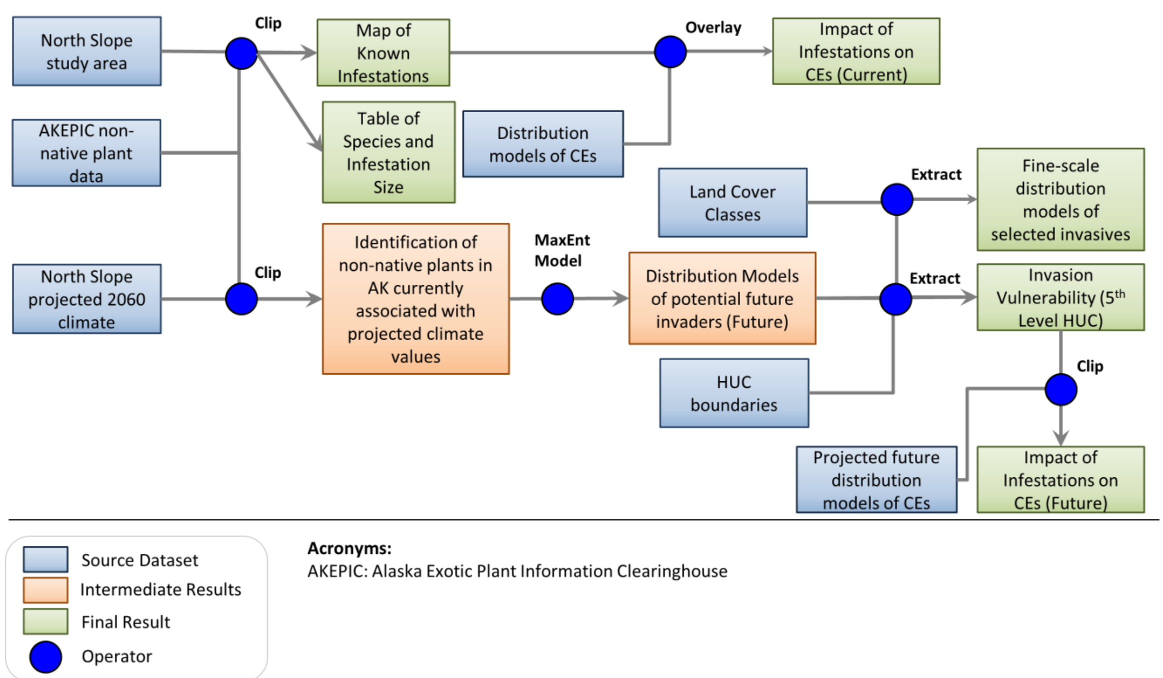
The first theme of current state of invasive species will be addressed by summarizing known locations, densities, and diversities of non-native species in tabular form and in maps. Short growing seasons and low temperatures are believed to limit the distribution of many invasive species in the region currently; future climate amelioration, however, is expected to increase suitability for many invasive species.[20,21] Identification of possible future invaders to this region, and generation of invasion vulnerability maps, will therefore be estimated by taking 2060 predicted growing season length, mean annual temperature, and mean July temperatures and identifying which species across Alaska are currently associated with those values or values of lower magnitude. This approach would therefore combine spatially explicit future climate models (SNAP) to identify maximum projected temperature and growing season length values in the region. Areas that currently have those values or less will then be identified and overlaid with non-native plant locations (AKEPIC), and the identity and number of records will be derived.[22] Areas with different levels of invasion vulnerability within the REA will then be delineated. Areas will be split into those in which no known invasive species are expected to occur, areas in which the climate is suitable for a small cohort (<10 species) of weakly to modestly invasive non-native species may occur, areas in which climate is suitable for a larger cohort (>10 species), and areas in which the climate is suitable for one or more species considered moderately to highly invasive. These broad regions may be further delineated into suitable and unsuitable habitat based on known or perceived association of the invasive species to particular land cover classes. For example, the highly invasive *Melilotus albus* is currently established just south of the REA boundary and is expected to be able to persist in the projected 2060 climate with the REA. However, this species is associated with exposed mineral soils such as floodplains.[23] Thus the predicted potential distribution of this invasive species would encompass floodplains and other barren land cover categories found within the appropriate climate envelope.

CE distributions can then be overlaid on invasion vulnerability maps to identify those species of conservation concern that may face a higher risk of having an important portion of their range impacted

[19] see Carlson and Shephard 2007, Schwörer et al. 2011
[20] see Carlson et al. 2014 (CBMP e-Newsletter)
[21] see Lassuy 2014 (CBMP e-Newsletter)
[22] see Lassuy 2014 (CBMP e-Newsletter)
[23] see Conn et al. 2008

by invasive species.

Process Model: Invasive Species Current and Predicted Future Condition Methodology



Limitations

Survey points for invasive plants are not random and many species are only recently introduced; therefore it is possible that documented locations do not represent the true breadth of their climate niche space. Additionally, the probability of invasive species establishment is largely driven by anthropogenic variables, such as population size and road density, elsewhere in the state.[24] With so few invasive species in the Arctic region, however, we are unable to determine the influence of anthropogenic factors on invasion probability. We therefore anticipate including the influence of anthropogenic factors in a descriptive manner, rather than explicitly attempting to include them in vulnerability maps.

Anthropogenic Uses

Anthropogenic uses in the region can broadly be classified into two types: Industrial and Non-industrial. Industrial activities include exploration for and extraction of natural resources such as oil, gas, and minerals. These uses account for a majority of anthropogenic activities in the region. The operations are complex and the impacts are multi-dimensional and varying in scale. Non-industrial activities include general habitation of population spread among ten permanent settlements across the vast region; subsistence and sport hunting and fishing activities; and transportation and communication infrastructure.

[24] see Invasive species section in Yukon-Kuskokwim-Lime Hills REA

Model Methods

Industrial activities:

Natural resource potential of the North Slope of Alaska is well recognized. Continuous exploration for and extraction of oil, gas, and minerals had a sustained impact on the ecosystems of the region over the course of the last century. While such activities were limited in scope before the discovery of oil at Prudhoe Bay, the region witnessed phenomenal growth in these activities since. Disturbances due to these activities felt at a landscape scale are the result of accumulation of a number of small related activities over a long period of time. For example, an oil field can be one small gravel pad with an access road, and the activity may not have a perceivable impact in isolation. However, a number of such gravel pads, access roads, associated pipelines, transportation infrastructure including trails, vehicular traffic, dust accumulation, material sites, gravel mines, sewage lagoons, reserve pits, small and large pollutant spills, seismic trails and snowpads together can have a sustained impact on the natural ecosystem.

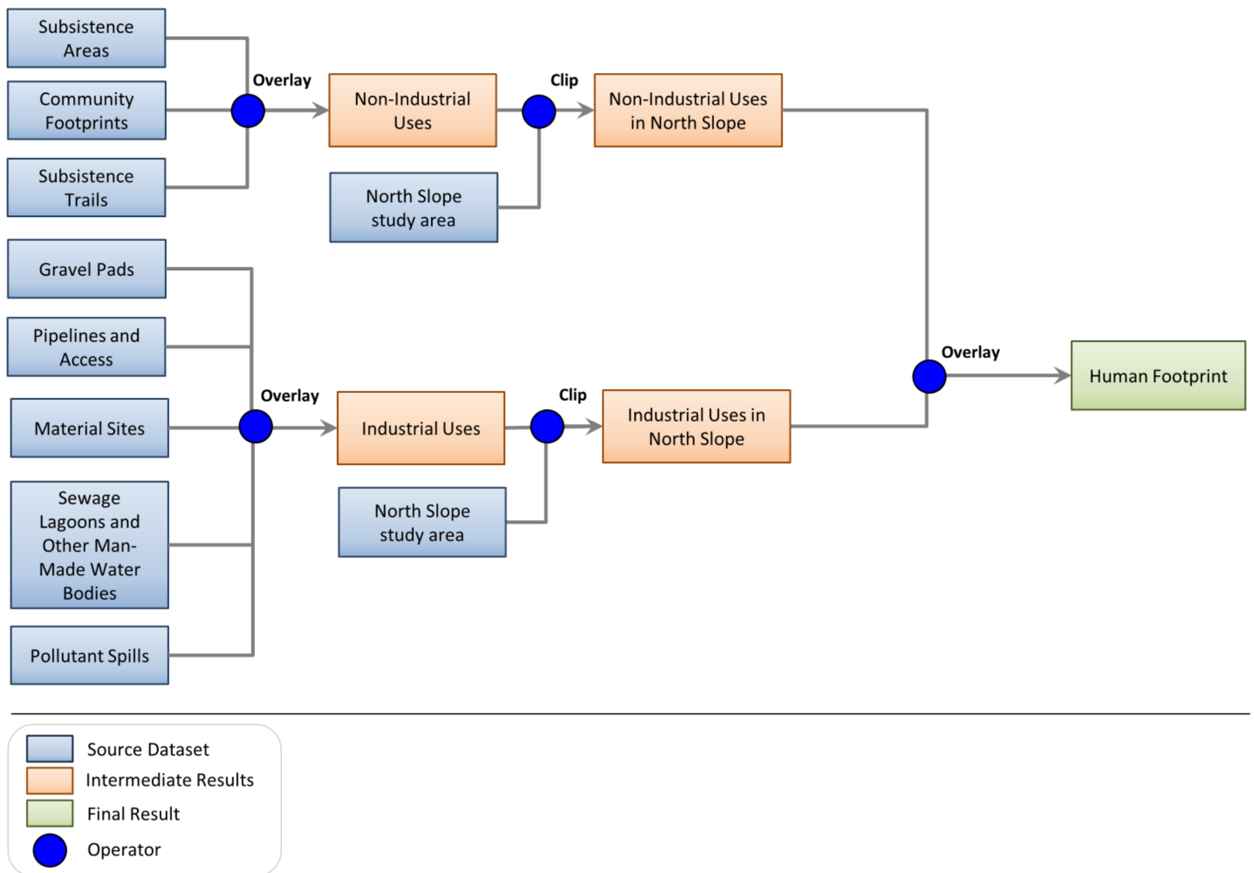
By 2001, the total area covered by oil and gas infrastructure in the study area was approximately 17,354 acres. This estimate includes areas affected by year-round structures and does not include seasonal and occasional activities such as ice roads or off-road travel. While the technology improvements over the last three decades have decreased the amount of such year-round infrastructure being built, it still remains high. In addition to extensive presence of oil and gas deposits, there are rich deposits of some of the best grade coal, and several minerals. Similar numbers are not readily available for mining activities in the region.[25]

Non-industrial activities:

All non-industrial activities result from general living of the local population in the region. The 2010 Census reports a total of 9003 people live in the study area, including 2174 workers at the Prudhoe Bay, the oil industrial complex. The remaining population lives in eight different communities. Barrow, the largest community, with a population of 4212, serves as the regional communication, transportation, and administrative hub. Point Hope, with 674 people, is the next largest and Atqasuk, with 233 people, is the smallest. None of the communities are connected by ground transportation but can be reached by air year-round. More than 80% of the population in all communities are Alaska Native, with the exception of Barrow. In Barrow, Alaska Natives comprise 61% of the population. While wage employment is higher in the region compared to other parts of rural Alaska, reliance on subsistence is high. Subsistence is of both economic and cultural value to the population. Non-industrial activities are generally confined to the community footprints. They include general community infrastructure including housing units, transportation facilities such roads and airports within the community footprint, and commercial and public facilities. Subsistence and recreation access trails extend beyond the community boundaries to reach hunting and fishing camps. Although the acreage under industrial development is quite large, it pales in comparison to the area required for subsistence. All four herds of caribou that range in the region are harvested for subsistence uses. Additionally, several other animal and bird species, plants, and berries are harvested.

[25] National Research Council 2003

Process Model: Comprehensive Human Footprint



Both industrial and non-industrial activities impact the ecosystem. The primary drivers of the impact from industrial activities include the construction, presence, and aging of structures in addition to pollutant spills (including oil and seawater spills), exploration activities such as drilling and seismic exploration, mining and redistribution of gravel, freshwater use and redistribution, noise and other disturbances due to transportation, and waste disposal. While the impact from non-industrial activities may be low in comparison, the primary drivers include increased income due to industry private sector jobs and the resulting infusion of cash that increases demand for local goods and services. The economic transformation of the North Slope from a subsistence-only economy prior to the oil boom to the current subsistence-cash mixed economy may have induced an irreversible change in the lives of the population. Community members are able to use modern technology to carry out their subsistence activities, allowing them to travel longer distances to access subsistence resources and harvest more.

In addition to the current footprint, potential development in the near and long-term will also be identified through review of proposed developments in the region. Proposed developments will likely be available from the North Slope Borough Planning Department, Alaska Department of Natural Resources, and press releases of private oil and gas companies. While effort will be spent in checking for accuracy of proposed development, it is to be noted that these future development scenarios will be speculative and liable to change due to various reasons. A comprehensive human footprint will be compiled from available information on all industrial and industrial anthropogenic activities in the region.

Limitations

A majority of the data will be obtained from the North Slope Borough Planning Department. The North Slope Borough is a municipal entity organized under the State Law and permits all land use in the region. The Department can provide a majority of the physical footprint data in spatial format. However, additional data will be needed to assess the physical extent of the human footprint. For example, unless the amount of water withdrawn and locations of the water sources for oil and gas activities are known, it is impossible to assess the impacts of water withdrawal. Such data are often proprietary and difficult to obtain. There may be several such data that may be unavailable for this assessment. Each data gap will be identified and documented.

Chapter 3: Conservation Elements

Conservation Elements (CEs) are defined as biotic constituents (i.e. wildlife and plant species or assemblages) or abiotic factors (i.e. soils) of regional importance in major ecosystems and habitats across the ecoregion. Selected CEs are meant to represent key resources in the ecoregion and may serve as surrogates for ecological condition across the ecoregion. CEs were identified through the MQs and/or were derived from the Ecoregional Conceptual Model to ensure the integration of practical management concerns with current scientific knowledge.

During Task 3, the UA Team and AMT identified both terrestrial and aquatic CEs for the ecoregion using a *coarse-filter – fine-filter* approach. This approach focuses on ecosystem representation as *coarse-filters* with a limited subset of focal species and species assemblages as *fine-filters*. The *coarse-filter – fine-filter* approach is closely integrated with many ecoregional and conservation modeling exercises.[26]

Terrestrial and Aquatic Coarse-Filter CEs represent the dominant ecological patterns of the ecoregion. Coarse-filter CEs include regionally significant terrestrial vegetation types and aquatic ecosystems within the assessment area. They represent the habitat requirements of most characteristic native species, ecological functions, and ecosystem services.

Fine-Filter CEs represent species that are critical to the assessment of the ecological condition of the North Slope study area for which habitat is not adequately represented by the Coarse-Filter CEs. Fine-Filter CEs selected for the North Slope REA are represented by regionally significant mammal, bird, and fish species.

Generally, we propose developing – or have already developed -- the following products for each CE: The status of each of these steps is indicated.

1. Mapping or modeling the **current distribution** of each CE. (Datasets have been identified for this purpose)
2. Creating **a conceptual model** based on the ecology of the species or landcover class and its relationship to CAs and drivers. (These have already been created; see Appendices A,B,C and D)
3. Identifying measureable **attributes and indicators** (environmental predictors) to assist with evaluation of status for each Fine-Filter CE. (Many of these have already been identified; work is in progress)
4. Intersecting the mapped distribution of each CE with those CAs identified as potentially significant through the CE-specific conceptual model and assessment of **attributes and indicators**. (This has yet to be completed, but the process will be described in Chapter 4: Integrated Products)
5. Assessing current, near term (2025), and long term (2060) **status** by similarly intersecting the mapped distribution of each CE with those CAs identified as potentially significant through the CE specific conceptual model and assessment of **attributes and indicators** under future

[26] Bryce et al. 2012

conditions. (This has yet to be completed, but the process will be described in Chapter 4: Integrated Products)

Conceptual Models

Conceptual models represent the state of knowledge about the relationships between the CEs, CAs, and other resources. Not all relationships identified lend themselves well to measurement or monitoring, but they are important to include because they add to our overall understanding of complex interactions.[27]

For each CE we produced a conceptual model that contains:

1) A textual description of the interrelationships between/among the CE, CA and other resources and their associated forms and processes.
2) A diagrammatic representation of the model, which includes information on how we anticipate the model being use for the REA. Most specifically the diagrams will address those relationships with the CAs that we will be able to assess in a spatial framework.
3) The basis and scientific support for the model.

Detailed conceptual models have been developed for each CE, supported and referenced by scientific literature, and are included in Appendices A, B, C, and D at the end of this document.

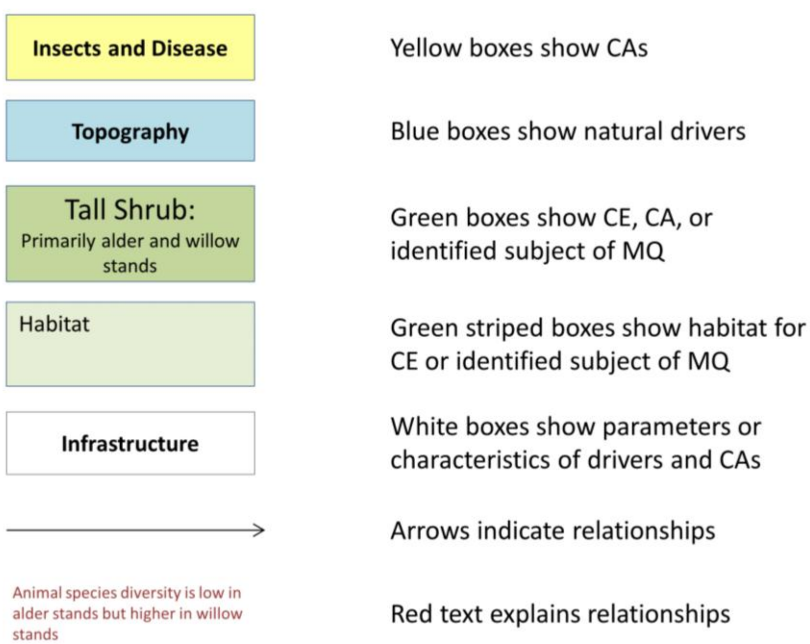


Figure 3: Conventions for conceptual models.

Conceptual models are diagramed according to the conventions outlined in Figure 3 above. The boxes indicate CEs, CAs, and drivers and arrows indicate regionally important interactions known to occur in

[27] Bryce et al. 2012

the North Slope study area. Text in dark red is positioned next to arrows to indicate the most likely relationships between constituents.

Attributes and Indicators

Ecological attributes are defined as traits or factors necessary for maintaining a fully functioning population, assemblage, community or ecosystem. On a species level, they are traits that are necessary for species survival and long-term viability. Indicators are defined as measureable aspects of ecological attributes. For REAs, we consider attributes and indicators as key elements that allow us to better address specific management questions, help parameterize models, and help explain the expected range of variability in our results as they relate to status and condition.

Attributes and indicators are a critical component of the core analysis as they help to define the relationships between conservation elements (CEs) and change agents (CAs), and, where possible, thresholds associated with these relationships.

For each Fine-Filter CE, we identified a number of attributes derived from the conceptual model, and assigned indicators based on available spatial data layers. Thresholds were set to categorize all data into standard reporting categories (i.e. indicator ratings). For some CEs, numerical measurements delineating thresholds were available from the literature. However, for many attributes/indicators, categories were generalized based on the best available information, and include (but are not limited to):

- Poor – Fair – Good – Very Good – Unknown – None/NA
- Low/none – Moderate – High – Very High – Unknown
- Present – Absent – Unknown

Categorization of attributes/indicators has been adopted as a required element for all REAs. Categorization allows data from a variety of sources to be organized similarly, whether the original data were collected in categories or were collected as numerical measurements. It also allows communication of information generated by complex REA analyses in an elegantly simple but meaningful manner, and helps to provide consistency in assessing and reporting across the variety of BLM resources, landscapes, and ecoregions.

We did not included attributes and indicators for Coarse-Filter CEs. Instead, Coarse-Filter CEs status will be assessed using Landscape Condition Models and Cumulative Climate Impacts (described in Chapter 4).

Here we provide an example (Figure 4) of an attribute and indicator for Willow Ptarmigan (*Lagopus lagopus*). This information is provided in summary table format for all Fine-Filter CEs, and is included with the individual CE conceptual model write-ups (see Appendices A, B, C, and D).

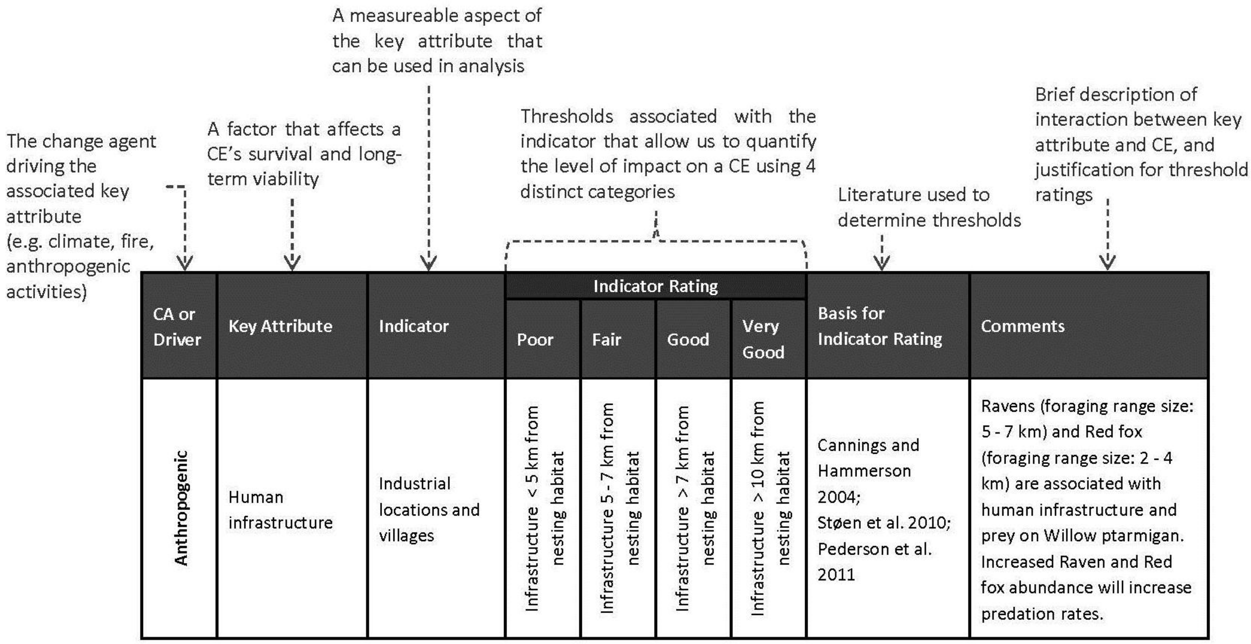


Figure 4. Explanation and example of attributes and indicators tables.

CE x CA Analyses

The conceptual model, literature synthesis, and attributes and indicators tables for each CE are available in Appendices A-D. The purpose of the CE specific assessment is to evaluate the current status of each CE at the ecoregional scale and to investigate how its status may change in the future as a result of future development and climate change. The conceptual model for each CE helps guide the selection of key ecological attributes and indicators that will assist us in assessing current and future status. Ecological attributes and associated indicators, at the fine-filter level, provide measures of the acceptable range of variation for each ecological attribute to further assist with assessment of status and trends.

In each of the Fine-Filter CE conceptual models, we have presented in **bold lines** those relationships that we intend to analyze spatially based on available datasets (measureable effects) as described in the attributes and indicators tables (Figure 5). Although these analyses will differ on a CE by CE basis, this process generally involves overlaying the distribution model for each CE with the measureable CA indicator (e.g., climate change, as indicated [measureable] by increases in spring precipitation and storm events, may affect juvenile mortality and reproductive success of Greater white-fronted geese).

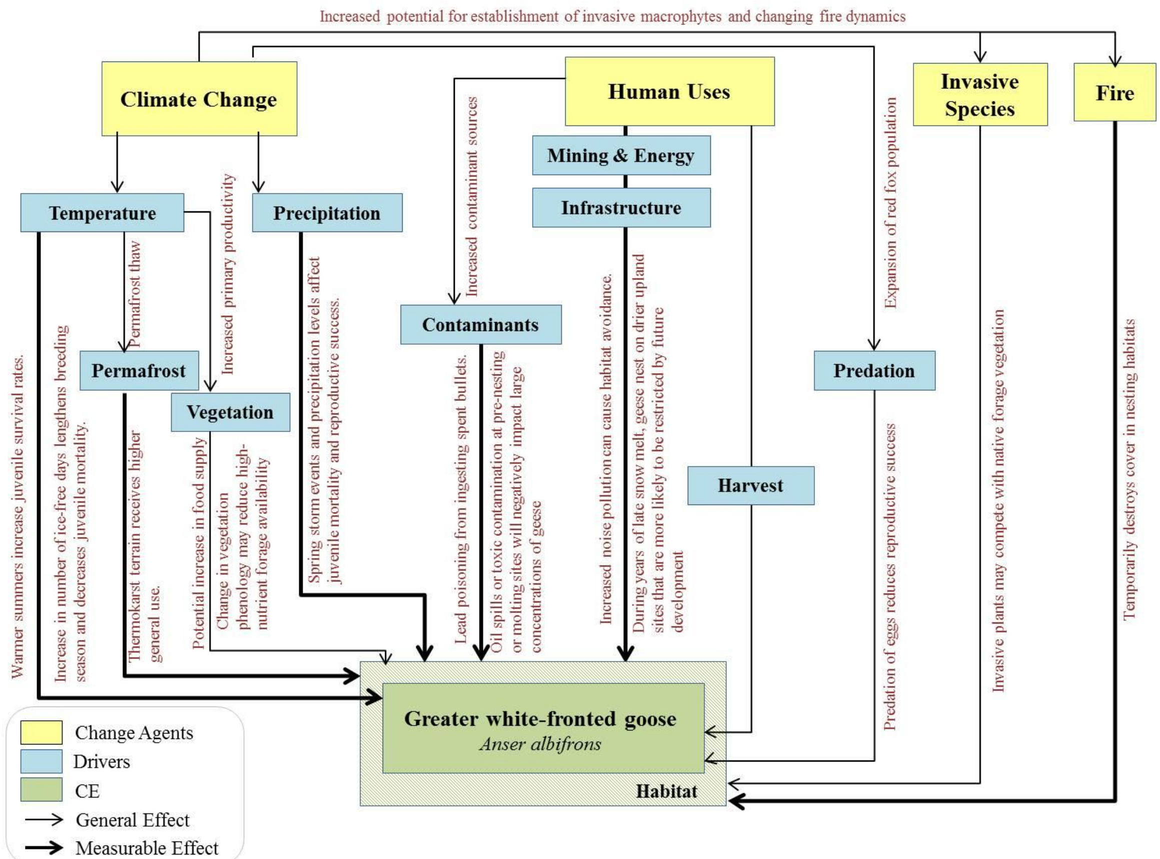


Figure 5. Example conceptual model for greater white-fronted goose.

Terrestrial Coarse-Filter CEs

Terrestrial Coarse-Filter CEs are regionally important Biophysical Settings (BpS) that represent the characteristic vegetation assemblages, succession, and dominant ecological patterns of the North Slope Ecoregion. They adequately address the habitat requirements of most characteristic native species, ecological functions, and ecosystem services. To develop a BpS map for the project area, we split the North Slope into dominant physiographic regions, and we described the dominant vegetation patterns and processes within each region (Table 3). This approach was originally developed by the BLM's Assessment Inventory and Monitoring (AIM) team as a stratification system for the long-term monitoring program in the National Petroleum Reserve – Alaska (NPRA). The goal of the AIM stratification was to reduce landscape heterogeneity by identifying landscape units with relatively similar vegetation, soil, and ecological processes.[28] Adopting this approach for the North Slope REA will allow us to more effectively evaluate the impacts of the selected CAs on vegetation pattern and composition.

[28] Toevs et al. 2011

Table 3. List of North Slope Biophysical Settings by physiographic region.

Physiography	Biophysical Setting
Coast:	Tidal Marsh BpS
	Marine Beach, Spit, and Barrier Island BpS
Coastal Plain:	Coastal Plain Wetland BpS
	Coastal Plain Moist tundra BpS
	Sand Sheet Wetland BpS
	Sand Sheet Moist Tundra BpS
Foothills:	Foothills Tussock Tundra BpS
Alpine:	Alpine Dwarf Shrub BpS
Floodplains:	Floodplain Shrubland BpS

Distribution Models

We will use four datasets to create BpS maps for the North Slope REA: the existing NSSI land cover vegetation map,[29] the National Wetlands Inventory map,[30] the ShoreZone dataset (Harper et al. 2013), and the Northern Alaska Subsections map.[31] We will develop the BpS map for the North Slope by following the steps outlined below:

1. **Tidal Marsh BpS:**
   a. Use the NWI tidal marsh and tide flat classes.
   b. Add NSSI Coastal Marsh class if it was not entirely captured by the NWI classes.
2. **Marine Beach, Spit, and Barrier Island BpS:**
   a. Use the ShoreZone environmental sensitivity index line feature as an overlay on the NSSI landcover map to identify beach, spit and barrier islands; ShoreZone polygon mapping is incomplete for the study area.
3. **Floodplain Shrubland BpS:**
   a. Use Floodplain Physiography class in the Northern Alaska Subsections map. Clip floodplains from the study area (bisects coastal plain, foothills, alpine).
   b. Within the clipped floodplain polygon, use the following NSSI landcover classes:
      i. Dwarf Shrub – Dryas
      ii. Dwarf Shrub – Other
      iii. Low-Tall Willow
      iv. Alder
      v. Sparsely Vegetated
      vi. Barren
   c. Note that Floodplain Wetland is a separate BpS that is not included or described.
4. **Split Coastal Plain from Foothills/Alpine:**
   a. Use the Coastal Plain Physiography class in the Northern Alaska Subsections map
   b. Result: Coastal Plain (plus sand sheet) polygon without floodplains, Alpine/Foothills polygon without floodplains.

[29] Ducks Unlimited 2013
[30] USFWS 2013
[31] Jorgenson and Grunblatt 2013

5. **Split Sand Sheet from the Coastal Plain:**
    a. Use Arctic Sandy Lowland class (Eco_Landscape) in the Northern Alaska Subsections map.
    b. Result: Sand Sheet polygon and Coastal Plain (no sand sheet) polygon without floodplains.
6. **Sand Sheet Wetland BpS:**
    a. Within the Sand Sheet polygon, use the following NSSI landcover classes:
        i. FWM: *Arctophila fulva*
        ii. FWM: *Carex aquatilis*
        iii. Wet sedge
        iv. Wet Sedge – Sphagnum
7. **Sand Sheet Moist Tundra BpS:**
    a. Within the Sand Sheet polygon, use the following NSSI landcover classes:
        i. Tussock tundra
        ii. Tussock Shrub Tundra
        iii. Mesic Sedge-Dwarf Shrub Tundra
        iv. Mesic herbaceous
        v. Birch Ericaceous Low Shrub
        vi. Dwarf Shrub – Dryas
        vii. Dwarf Shrub – Other
        viii. Sparsely Vegetated (dunes and drained lakes)
        ix. Barren (dunes and drained lakes)
8. **Coastal Plain Wetland BpS:**
    a. Within the Coastal Plain (no sand sheet) polygon, use the following NSSI landcover classes:
        i. FWM: Arctophila fulva
        ii. FWM: Carex aquatilis
        iii. Wet Sedge
        iv. Wet Sedge – Sphagnum
9. **Coastal Plain Moist Tundra BpS:**
    a. Within the Coastal Plain (no sand sheet) polygon, use the following NSSI landcover classes:
        i. Tussock tundra
        ii. Tussock Shrub Tundra
        iii. Mesic Sedge-Dwarf Shrub Tundra
        iv. Mesic herbaceous
        v. Birch Ericaceous Low Shrub
        vi. Dwarf Shrub – Dryas
        vii. Dwarf Shrub – Other
        viii. Sparsely Vegetated (drained lakes)
        ix. Barren (drained lakes)
10. **Foothills Tussock Tundra BpS:**
    a. Within the Foothills/Alpine polygon, use the following NSSI landcover classes:
        i. Tussock tundra
        ii. Tussock Shrub Tundra
        iii. Mesic Herbaceous
        iv. Mesic Sedge-Dwarf Shrub Tundra
11. **Alpine Dwarf Shrub BpS:**
    a. Within the Foothills/Alpine polygon, use the following NSSI landcover classes:
        i. Dwarf Shrub – Dryas
        ii. Dwarf Shrub – Other

We made the following changes to the BpS CE list between Memo 2 and Memo3: 1) We split the Sand Sheet from the Coastal Plain, adding 2 new BpS classes, Sand Sheet Wetland and Sand Sheet Moist Tundra; 2) We combined the Inland Dunes BpS with the Sand Sheet Moist Tundra because we determined that the dunes could not be mapped using the NSSI landcover map, and they are functionally associated with the sand sheet; and 3) We substituted Alpine Dwarf Shrub for Alpine Barrens as the representative alpine class because it is a matrix alpine class with high value as wildlife habitat.

We will use the Biophysical Setting map to delineate the Coarse-Filter CEs.

Limitations

The NSSI landcover map (Figure 6) provides coverage of the coastal plain and foothills region of the NOS REA project area; however, at the southern boundary of the project area, in the Brooks Range Mountains and in the Noatak Basin, there are gaps between the landcover map and the project boundary. We will mosaic the Interior Alaska statewide mosaic landcover map[32] with the NSSI map to create a complete coverage of the project area.

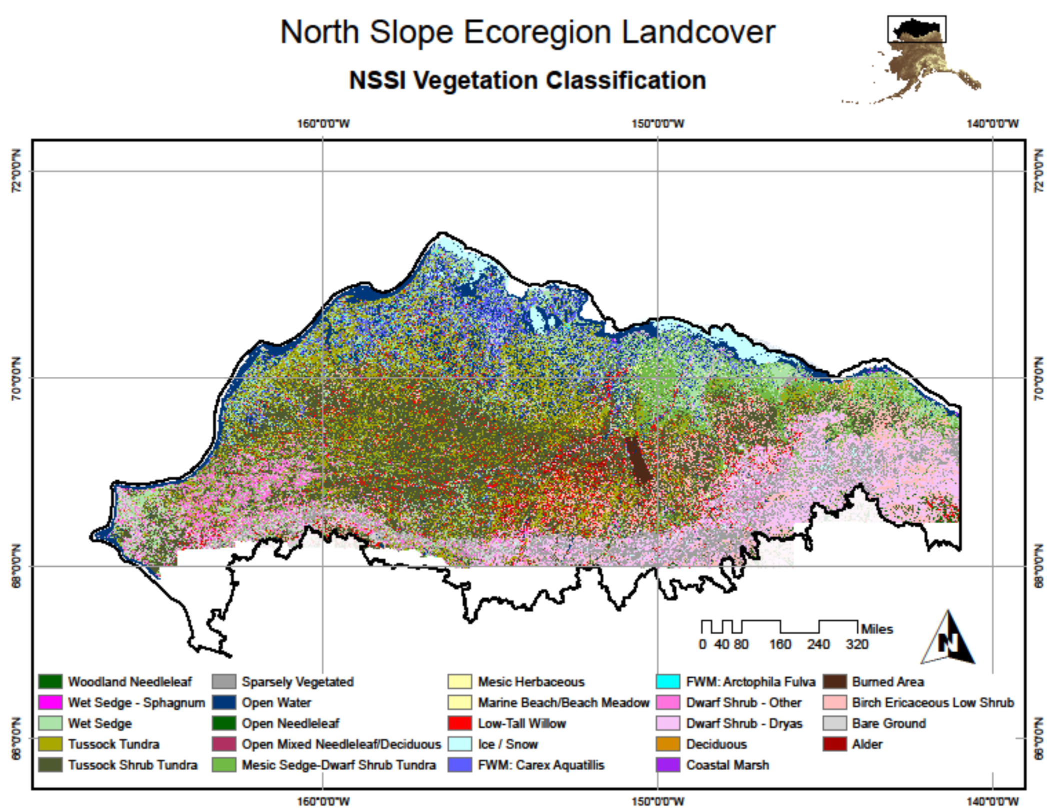


Figure 6. NSSI landcover map showing the data gap at the southern boundary of the project area.

[32] Boggs et al. 2012

Aquatic Coarse-Filter CEs

Four habitat types were selected as Aquatic Coarse-Filter CEs:

1. large streams
2. small streams
3. deep connected lakes
4. shallow connected lakes

The NOS lacks the aquatic habitat map necessary to define Aquatic Coarse-Filter CEs by habitat. Thus, the Aquatic Coarse-Filter CEs have been identified as a **data gap** due to the lack of an aquatic habitat map for the NOS REA study area. The limitations of this mapping effort are summarized below.

Distribution Models

In addition to the limitations of the data available for mapping aquatic habitats (see Limitations below), it is beyond the scope of this project to create an aquatic habitat classification relating aquatic habitat types to physical, chemical, and biological conditions for the NOS REA. Instead of creating a map of aquatic habitats that would have spatial inaccuracies and lack necessary field descriptions, we have proposed to summarize available data for 5th level HUCs across the NOS REA study area. This would include published information on hydrologic regime, water quality, physical habitat, and biological communities.

Limitations

The NHD is the best available spatial data of aquatic resources for the NOS REA. It is a digital representation of the stream network and lakes shown on USGS topographic maps, which were created from historic aerial photos. It has several limitations:

a. The NHD underrepresents small streams because they are often masked by vegetation cover and not visible in aerial photography.
b. The NHD is very outdated (most topographic maps were created in the 50's and 60's) and stream locations and lake areas have likely changed due to natural hydrologic disturbances and climate change.
c. Both stream order and stream gradient are needed to map aquatic habitats; the NHD is not attributed with stream order and does not align with valley bottoms in the digital elevation model (DEM) so stream gradient cannot be calculated accurately.

Additionally, the best available DEM for the study area is the National Elevation Dataset (60 m pixels). Due to the limitations of the NHD, aquatic habitats must be mapped by creating a stream network from the DEM, which has its own set of drawbacks.

a. Utilizing a coarse DEM to map streams results in a gross oversimplification of the stream network length and complexity.
b. The DEM does not match the NHD, which is the best available representation of what exists on the ground.
c. When creating a stream network from a DEM, a decision must be made regarding the size of the

watershed required to initiate a first order stream. There is no available data relating area to perennial flow initiation for the study area and due to the diversity of topographic, geologic, and permafrost characteristics across the NOS REA ecoregion, this relationship is expected to vary.

The lack of a statewide aquatic habitat classification represents a huge **data gap** that could be preventing more effective management of aquatic habitat resources. This is especially important given the spatial inaccuracies and limited attribute information in NHD that can be used to map aquatic habitats. Additionally, due to the spatial resolution of the most current DEM, we are not able to build a stream network that could aid mapping of aquatic habitats. Furthermore, no aquatic habitat descriptions are available to justify creating an aquatic habitat map.

Limited information exists for specific threshold effects of attributes and indicators for Coarse-Filter CEs. Currently there are no climate change predictions specific to aquatic habitats, such as changes to water temperature or hydrologic regime. There is limited survey information on aquatic invasive species for the study area, even though the assumption is they are not there.

Terrestrial Fine-Filter CEs

Seven species were selected as Terrestrial Fine-Filter CEs for the North Slope REA. An effort was made to select species representative of different ecological niches. For example, Greater white-fronted geese broadly represent waterfowl resources for the REA.

1. Caribou (*Rangifer tarandus*)
2. Nearctic brown lemming (*Dicrostonyx trimucronatus*)
3. Arctic fox (*Vulpes lagopus*)
4. Lapland longspur (*Calcarius lapponicus*)
5. Raptor assemblage
6. Willow ptarmigan (*Lagopus lagopus*)
7. Greater white-fronted goose (*Anser albifrons*)

Distribution Models

Our goal is to generate a distribution map for each CE using existing datasets. For most CEs, existing distribution models were available from the Alaska Gap Analysis Project. Alaska Gap (AKGAP) models are spatial representations of a species predicted distribution, within known range limits, at 60 m pixel resolution. Models were generated through a combination of deductive and inductive modeling techniques,[33] and have been statistically assessed for accuracy and peer reviewed. It is important to note that the AKGAP models were developed to depict the species (CE) distribution across its full range in Alaska, not specifically within the NOS REA boundary. Although the distribution models were designed to be used for large-area resource management planning, we cannot guarantee the accuracy of the models once they are constrained by (clipped) to the NOS REA boundary. In an effort to establish that the models are suitable at the scale of the NOS REA, we are also compiling existing occurrence datasets

[33] Gotthardt et al. 2013

to perform an independent accuracy assessment of each model that is specific to the REA. The AKGAP models will be clipped to the NOS REA boundary and then assessed for accuracy using presence (occurrence) data and randomly generated pseudo-absences that will be overlaid with model outputs. Model performance will be calculated using a confusion matrix and its metrics. The confusion matrix calculates the percentage of true negatives, true positives, false negatives and false positives from Receiver Operating Characteristics (ROC) to produce an area-under the curve (AUC) value. AUC values range from 0.5 (random) to 1.0, with values of .75 or greater generally considered good model fit.

If accuracy assessment values are acceptable, we intend to use AKGAP distribution models for Nearctic brown lemming, Arctic fox, Lapland longspur and Willow ptarmigan. If not acceptable, distribution will be represented by the synthesis of occurrence data gathered for each species to generate assessment datasets. For the Greater-white fronted goose, we obtained a breeding density distribution map that is specific to the North Slope, based on data collected and analyzed by USFWS (Platte, unpublished data), which we feel is a much more accurate representation of the species habitat utilization than the AKGAP model. The AKGAP distribution models for raptors are generally of poor quality, as cliff nesting features were not mapped well. Therefore, the distribution of raptor concentration areas will be mapped using existing occurrence data only. The seasonal distribution of caribou will be derived from radio-collar data and existing range maps. Associated methods to map the distribution of caribou are presented in detail under MQ TF 4.

Limitations

As described above, the greatest limitation with using the AKGAP distribution models is the statewide scale at which the models were developed, and whether or not the mapped products are appropriate at the scale of the NOS REA study area. To ensure that they are suitable for the REA, we will assess the accuracy of the models using independent data (as described above) and also solicit expert review of the modeled outputs. LandFire was the primary landcover map used to develop the AKGAP models, which has been criticized for its low accuracy. However, at the time of our modeling, it was the finest scale statewide landcover map available. For our purpose, which was to develop range-wide distribution models at a coarse scale, we felt that LandFire captured the general vegetation pattern of the landscape and appeared accurate and generally suitable for portraying vertebrate distributions at these scales. Furthermore, in an attempt to compensate for some of the deficiencies associated with LandFire, we included additional habitat variables in our models, such as hydrological characteristics, human avoidance characteristics, forest interior and ecotone width, and association with edges (derived from NLCD).

Limited information exists on threshold effects of indicators on key ecological attributes. In many instances we have used home range size of the individual CE, based on literature review, to designate the potential extent of an effect.

Aquatic Fine-Filter CEs

Five species were selected as Aquatic Fine-Filter CEs. An effort was made to select representative species from different taxonomic groups (either family or sub-family).

1. broad whitefish (*Coregonus nasus*)
2. Dolly Varden (*Salvelinus malma*)
3. chum salmon (*Oncorhynchus keta*)
4. arctic grayling (*Thymallus arcticus*)
5. burbot (*Lota lota*)

Distribution Models

For each species, a distribution map will be created. The Alaska Department of Fish and Game (ADF&G) maintains the Anadromous Waters Catalog (AWC), which contains the spatial distribution of anadromous fish species across the state. The AWC will be used to represent the distribution of broad whitefish, Dolly Varden, and chum salmon within the NOS REA. Arctic grayling and burbot are not covered by the AWC. In order to develop distribution maps for these two species, we will use data obtained from the ADF&G's Alaska Freshwater Fish Inventory and the Alaska Lake Database. The distribution of Fine-Filter CEs will be amended with additional occurrence points and spawning sites using published and unpublished data.

Limitations

No complete spatial distribution data for fish species currently exists, limiting habitat distribution modeling efforts. Additionally, outside of commercial and subsistence fish species, almost no information on population sizes for other fish species exist. Information on the extent of anadromy or amphidromy for Dolly Varden and broad whitefish populations are limited and almost nothing is known about chum salmon overwintering habitat within the NOS REA. Distribution data on burbot are especially limiting given that they are not covered by the AWC and other sources for distribution data are scarce.

Limited information exists for specific threshold effects of attributes and indicators for Fine-Filter aquatic CEs. For example, there are few climate change predictions specific to each aquatic Fine-Filter CE, such as changes in winter precipitation and direct affects to species. Furthermore, water temperature data for aquatic habitats is lacking in the NOS REA study area, thus air temperature is used as a proxy for interpreting changes in water temperature and the potential effects on CEs.

Chapter 4: Integrated Products

Landscape Integrity

Ecological *integrity* was originally proposed in the scope of work provided by the BLM. However, we feel it is not appropriate to assess ecological integrity in the North Slope for the following reasons:

- The timeframe of an REA is insufficient to perform a proper classification of ecological condition.[34]
- Measurements of ecological *integrity* require indices of biological condition that must be supported by extensive data collection efforts, which are outside of the scope of the REA.

The concept of landscape integrity, on the other hand, is useful in meeting the primary objective of documenting the current and potential future status of selected ecological resources. Landscape integrity can be easily calculated using existing datasets, yet is robust enough to be used in current and future scenario geospatial models. Landscape integrity provides a quantifiable and readily assessable measure of naturalness, or put more simply, a measure of how contiguous a landscape is (i.e. the fragmentation of an ecosystem). Landscape integrity will be modeled with parameters that are amenable to measurement, monitoring, scoring, and adaptive management. Future data will therefore have the potential to inform the landscape integrity model, producing updated results that will enable land managers to visualize the current and future status of the landscape. We propose modeling landscape integrity in three ways: **Landscape Condition Model**, **Conservation Element Status**, and **Cumulative Climate Impacts** for the three time periods: current, near-term (2025) and long-term (2060).

Landscape Condition Model

The Landscape Condition Model (LCM) is a simple yet robust way to measure the impact of the human footprint on a landscape.[35] The LCM categorizes human modifications into different levels of impact (site impact score), based on the current state of knowledge about the impacts of specific human land uses (

Table 4) collected from thousands of papers spanning many types of habitats and contexts. Permanent human modification is weighted the highest, while temporary use (such as snow roads and snow machine trails) receive less weight. Intensive land uses, such as mining, are also weighted higher than less intensive land uses, such as hunting cabins. In addition to describing the relative impact of each land use, the LCM also identifies a distance at which the impact is no longer exhibited on the landscape (decay distance), again based on extensive meta-analysis of the impacts on many species/habitats/contexts. For the purpose on this assessment, we assume a linear distance decay function (gradual decrease in impact as you move further from the activity until you reach the maximum distance at which the impact is negligible).

[34] Rocchio and Crawford 2011
[35] Comer and Hak 2009

Table 4: List of human modification variables used in the Landscape Condition Mode (LCM) from Comer and Hak (2012), but modified based on availability of datasets and presence of specific threats. Decay scores with an * are modified from original LCM literature for Alaska conditions, based on research by Strittholt et al (2006).

Theme	Data Source	Site Impact Score	Est. Relative Stress	Decay Distance (m)
Transportation				
Trails	AK DNR/TIGER	0.7	Low	500*
Dirt roads, 4-wheel drive	AK DNR/TIGER	0.5	Low	500*
Local and connecting roads	AK DNR/TIGER	0.5	Medium	500*
Haul Road	AK DNR/TIGER	0.2	High	2500*
Urban and Industrial Development				
Medium Density Development	NSSI Landcover	0.3	Medium	1000*
Powerline/Transmission lines	USGS/AK DNR	0.5	Medium	500*
Oil /gas Wells	BLM/AK DNR	0.5	Medium	500
Historic Mines	ARDF/BLM/State	0.5	Medium	500
Current Mines	ARDF/BLM/State	0.05	Very High	1500*
Managed and Modified Land Cover				
Introduced Vegetation	NSSI LC/AKEPIC	0.5	Medium	200

Furthermore, we propose slight modification to the default distance distances applied in the LCM to better represent conditions in Alaska. Specifically, the decay distance associated with major roads is thought to be much larger due to the extensive use of ATVs and snow machines by Alaskans.[36] We extend this increase to some of the other road types as well as the urban land uses, as snow machines and ATV use is not excluded to major roads. By applying these different impact and decay scores to the various land uses, a surface raster representing the relative condition of the landscape, scored 0 (for very low condition) to 1 (very high condition), is created. Where two or more land uses and their decay scores overlap, we propose using the minimum (thus the highest impact) score, assuming that high-impact features are not additive. The LCM will then be summarized per 5th-level HUC (Figure 7) to facilitate use in the assessment of CE status (see CE Status section below).

[36] Strittholt et al. 2006

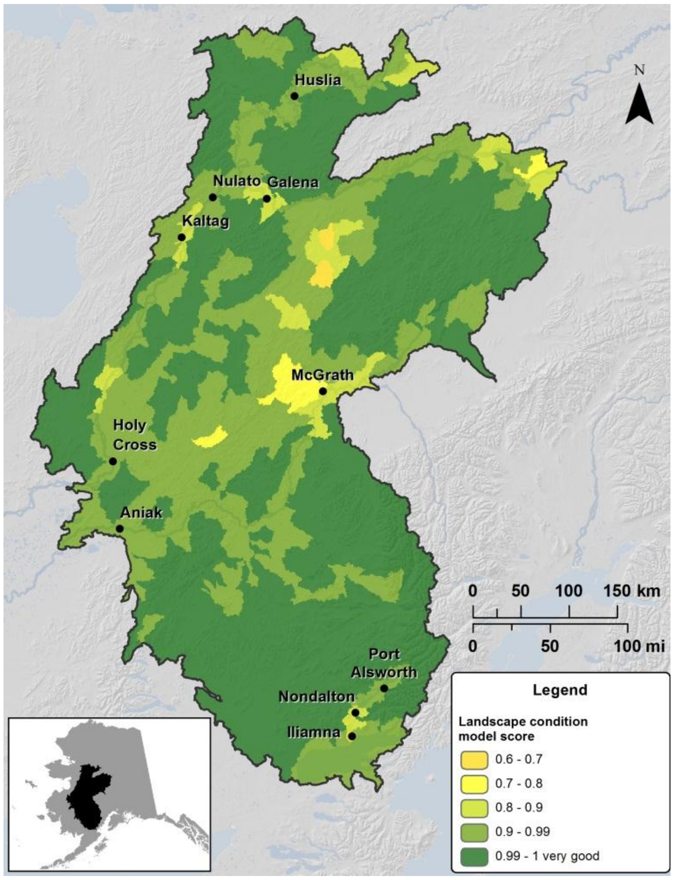


Figure 7: Near Term (2025) Landscape Condition Model summarized at 5th-level HUCs for the Yukon, Kuskokwim, Lime Hills REA. Low scores indicate poor condition, while larger scores (approaching 1) represent good condition landscapes.

However, merely considering the condition without considering the landscape context may misrepresent the actual impact of different human activities on the overall landscape integrity. Most importantly, landscape condition should not be assessed at a particular location without some explicit consideration of the surrounding environment.[37] To address this, we suggest identifying large, intact blocks by extracting contiguous areas that have a LCM score in the top 20% for the ecoregion. We propose using three size thresholds to correspond to other efforts that have taken place in Alaska to map unfragmented habitats (Table 5). First, we propose looking at blocks that are greater than or equal to 50,000 acres to coincide with the Global Forest Watch program from the World Resources Institute and their Intact Forest Landscapes.[38] Second, we propose looking at blocks that are less 50,000 acres but greater than or equal to 10,000 acres to correspond to previous wilderness area designations studies.[39] Third, we will identify all the blocks that are less than 10,000 acres as potentially vulnerable to disturbances.

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[37] Scott et al. 2004
[38] Strittholt et al. 2006
[39] Geck 2007

Table 5: Proposed categories for assessing large intact blocks of habitat.

Size	Designation
≥ 50,000 acres	Highest Landscape Integrity
< 50,000 acres, ≥ 10,000 acres	High Landscape Integrity
< 10,000 acres	Vulnerable to change

Conservation Element Status

We propose to assess CE status by modeling all known impacts (identified in the attributes and indicators table) for each individual Fine-filter CE independently. Previous REAs have assessed status by overlaying the LCM with the species distribution. While this is a reasonable estimate of habitat status in the lower 48, the human footprint is greatly reduced in Alaska. However, despite the limited human impact, habitats can still be impacted by various biotic and abiotic features on the landscape.

Thus, we propose modeling every indicator in the attributes and indicators table as a GIS dataset according to the indicator rating (poor, fair, good, very good habitat). Status will then be inferred by summing those indicators, again using the minimum score for any given location on the map, to provide an estimate of CE status. This approach not only allows us to focus more intently on published established responses of CEs to various CAs, but it also allows us to model the future status as a function of all the CAs.

However, Coarse-Filter CEs are by definition assemblages of species or biophysical properties that define larger communities or habitat types. Thus, no single set of attributes or indicators can be developed for Coarse-Filter CEs. In order to assess the status of Coarse-Filter CEs, we propose using both the Landscape Condition Model (LCM) and the Cumulative Climate Impacts (CCI). For each Coarse-Filter CE, we will classify the distribution using both LCM and CCI scores that will reflect the overall impact of human footprint and climate change.

Cumulative Climate Impacts

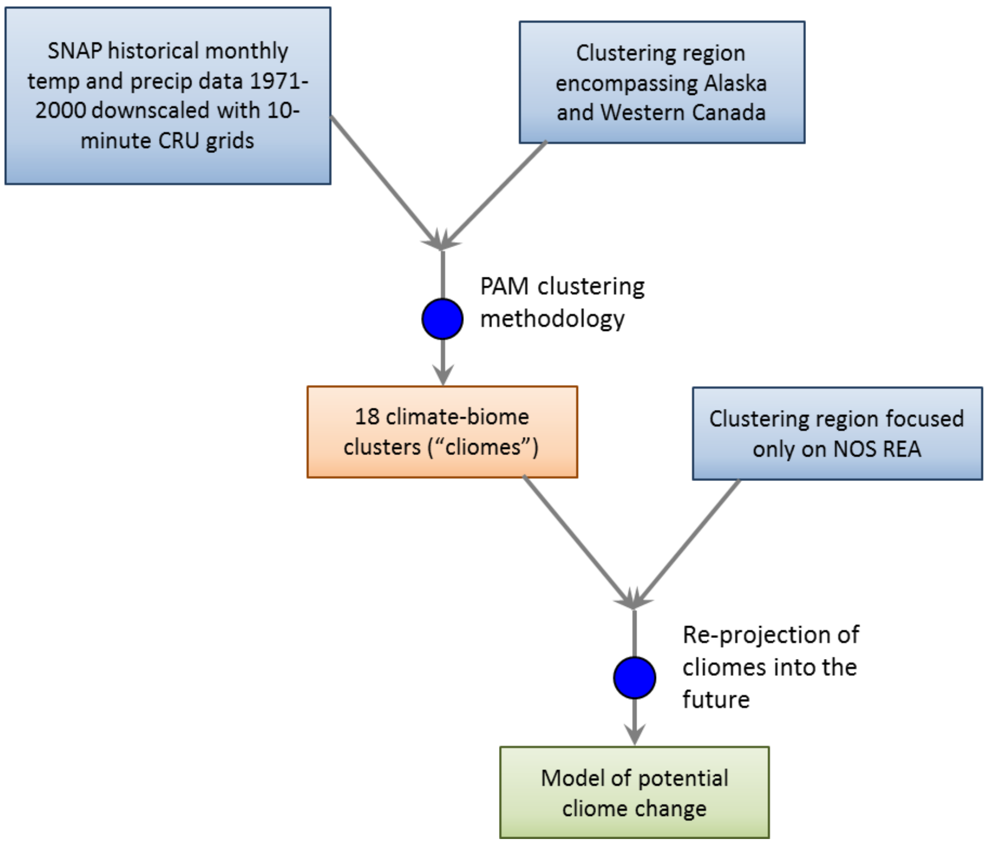
The final integrated product we proposed developing is called the Cumulative Climate Impact (CCI). The concept behind the CCI is that CAs will not change sequentially, nor will they change independently. Future environments will be shaped by all the CAs interacting and changing together to create a new landscape. To identify where those new landscapes are most likely to occur, we propose combining all climate variables into a single measure (cliomes), and relating those to both fire and permafrost (since both are highly dependent upon climatic drivers).

The Alaska Climate-Biome Shift Project (AK Cliomes) was a collaborative effort that used clustering methodology, existing land cover designations, and historical and projected climate data to identify areas of Alaska that are likely to undergo the greatest or least ecological pressure, given climate change.[40] The clusters or "cliomes" used in the model are machine-generated groupings of areas with similar climates. The eighteen cliomes were identified using the combined Random Forests™ and PAM

[40] SNAP and EWHALE 2012

clustering algorithms, and are defined by 24 input variables (monthly mean temperature and precipitation) used to create each cluster. Cliomes can be considered to be broadly defined regions of temperature and precipitation patterns, and serve as indicators of potential change and/or stress to ecosystems.

Process Model: Cliome Shift Methodology



We propose using these clusters as proxies for how much climate (and thus fire and permafrost) will change on the North Slope. Specifically, we propose using a multivariate measure to understand the "distance" between climate clusters. Using this "distance", we will then be able to identify what regions of the North Slope are likely to change the most. This effort, taken in concert with the LCM, will provide land managers with a comprehensive picture of where the most vulnerable (to change) landscapes are likely to be in the near and long-term.

Limitations

While considered a robust way to measure naturalness, there are some key assumptions made in the conceptualization of landscape integrity. While obvious at a local scale, human footprints are not always well mapped or captured in a geospatial framework. This is especially true for historical human use (i.e. native use, or even modern historical use prior to the establishment of environmental monitoring programs). Thus, our landscape integrity model assumes that the current and historical human footprint is accurately modeled for the region. This is especially relevant as one of the key outputs from an REA is a better understanding of the indirect impacts of human activity on ecosystems.

Furthermore, given the cross-disciplinary nature of the core REA analyses, there exists a high potential for error. Modeled outputs will be placed into other models, each with different assumptions, potentially propagating errors throughout. Using GIS as a common platform can assist in identifying errors early in the modeling process, and (by creating intermediate data products) provides a transparent process in which critical review of our assumptions can be made. Thus, while many of these models were never designed to interact, we feel confident that all our modeling efforts represent the best available knowledge about the system and the potential impacts of the “known and unknown unknowns”.

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Appendix A: Conceptual Models for Terrestrial Coarse-Filter CEs

Conceptual Models and model descriptions for the following North Slope Biophysical Settings (BpS):

Tidal Marsh
Marine Beach, Spit, and Barrier Island
Coastal Plain Wetland
Coastal Plain Moist tundra
Sand Sheet Wetland
Sand Sheet Moist Tundra
Foothills Tussock Tundra
Floodplain Shrubland
Alpine Dwarf Shrub

Appendix A. Figures

Tidal Marsh

Background

Tidal marshes bordering Alaska's Arctic Ocean form a narrow band along the coastline. As an interface between ocean and land, tidal marshes combine aquatic and terrestrial habitats, anoxic and oxic conditions, as well as saline and fresh waters (Stone 1984). This dynamic environment supports life highly adapted to saturation and brackish or saline conditions. Although tidal marshes and flats only occupy a small percentage of the total landscape, they are a critical staging area for migrating shorebirds, geese and swans, and also support several species of conservation concern – such as the Steller's Eider. Tidal marshes are one of Alaska's most impacted habitats due to rapid coastal erosion (Jones et al. 2008, Ping et al. 2011, Forbes 2011) caused by diminishing sea ice, sea level rise and melting permafrost.

Environmental Characteristics:

Tidal marshes may occur wherever there is relatively flat land at sea level that receives periodic input of tidal waters (Frohne 1953). Arctic tidal marshes are unique from their more southerly, subarctic counterparts in that they form primarily as a narrow fringe (<10 m wide) along tidal river channels, inlets, tidal lagoons protected by barrier islands, and also on salt-killed tundra. This unique and reduced marsh development may be partially due to shallow tidal range (e.g., 0.01 m at Prudhoe Bay in the north, compared to 4.5 m at Nushagak Bay in the southwest; NOAA 2013). The shallow tidal range and low-angle topography reduces the elevational range across which tide marsh Plant Associations occur and expands the inland extent of tidal influence along rivers.

The development of tide marshes in northern Alaska is also limited by coastal erosion, which at rates of 1.2 m/year from 1980-2000 (Forbes 2011, Jones et al. 2008, Ping et al. 2011) truncates the seaward expansion of marsh systems. High rates of coastal erosion relate to the combined factors of global sea level rise, increase in ice free days and permafrost degradation. Higher relative sea level extends the impacts of storm surges and facilitates the degradation of permafrost. Storm surges 2-3 m above sea level flood coastal and low-lying inland tundra (Taylor 1981); permafrost degradation along the coast allows inundation of nearshore basins, polygonal ground and tussock tundra (Bergman et al. 1977, Jorgenson and Miller 2010). Exposure of tundra vegetation to saltwater weakens or kills the resident species and allows salt-tolerant species to colonize (Bergman et al. 1977, Jorgenson et al. 1994, Kincheloe and Stehn 1991). Similarly, an increase in ice-free days exposes the coastline to coastal erosion, ice rafting and storm surges for a greater period of time, thereby exacerbating the cumulative impacts of these processes.

Arctic tidal marshes receive fresh water from streams and rivers, as well as overland and subsurface flow during spring and summer runoff (Meyers 1985, Kincheloe and Stehn 1991). Water salinity is inversely related to freshwater inputs and is subsequently lower in the spring when freshwater contributions from melting ice and snow are higher (Jefferies 1977).

Permafrost is present in most arctic tidal marshes (Jorgenson et al. 2004, 2009), and due to the warming effects of water, active layer depth increases with proximity to water bodies (Bergman et al. 1977, Hanson 1951, Kincheloe and Stehn 1991). Shallow permafrost promotes the inundation of tidal marshes by restricting drainage (Bergman et al. 1977, Meyers 1985).

Climate:

The coast of Alaska along the Arctic Ocean has dry polar conditions with short, cool summers and long, cold winters. Average summer temperatures range from 0 to 15 °C; average winter temperatures are between -30 and -21 °C. Freezing can occur in any month of the year but July and August are generally frost-free. Annual precipitation is 14 cm with 30-75 cm received as snow. Proximity to the Arctic Ocean and abundant sea ice contribute to increasing fog in August. Winds are persistent and strong (Gallant et al. 1995, Nowacki et al. 2001).

Vegetation:

General tidal vegetation zonation patterns are recognizable within Arctic Ocean tide marshes (Boucher 2013, Jefferies 1977, Jorgenson et al. 1994, 1997, Jorgenson 2003, Meyers 1985, and Taylor 1981). Below we provide two physiographic and vegetation profiles; the *Puccinellia phryganodes* and the *Carex subspathacea–Carex glareosa* associations. The *Puccinellia phryganodes* association typically occurs in the lower-tidal zone. *Puccinellia phryganodes* may form a dense turf or be present only as scattered runners in more exposed sites. Species diversity is low and includes *Calamagrostis holmii, Sagina nivalis* and *Stellaria humifusa*.

The *Carex subspathacea* and *Carex glareosa* associations typically occur in the mid-tidal zone on subsiding tundra, salt-killed tundra or on sand recently deposited from shifting beaches and coastal dunes. *Carex ursina* may codominate (Jorgenson et al. 1997). The *Dupontia fisheri* association also occurs in the mid-tidal zone where codominant species may include *Stellaria humifusa* or *Carex ursina*.

The *Carex subspathacea-Salix ovalifolia* association occurs in the upper tidal zone on subsiding tundra, salt-killed tundra, along banks of tidal rivers or on sand recently deposited from shifting beaches and coastal dunes. Both *Salix ovalifolia* and *Carex subspathacea* have greater than 25% cover. On subsiding tundra sites, non-tidal species (e.g., tundra species) such as *Carex aquatilis, Eriophorum angustifolium, Chrysanthemum arcticum* and bryophytes such as *Campylium stellatum* and *Meesia triquetra* may be common.

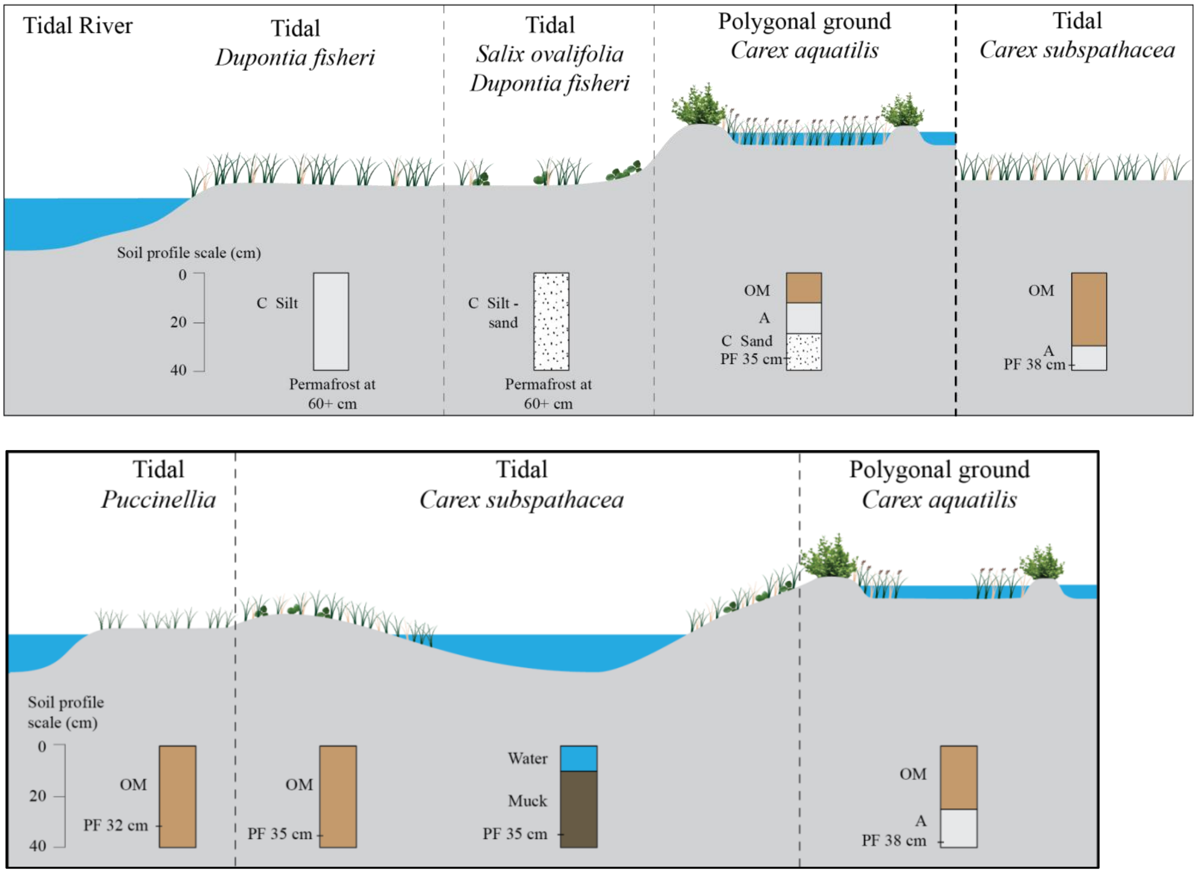
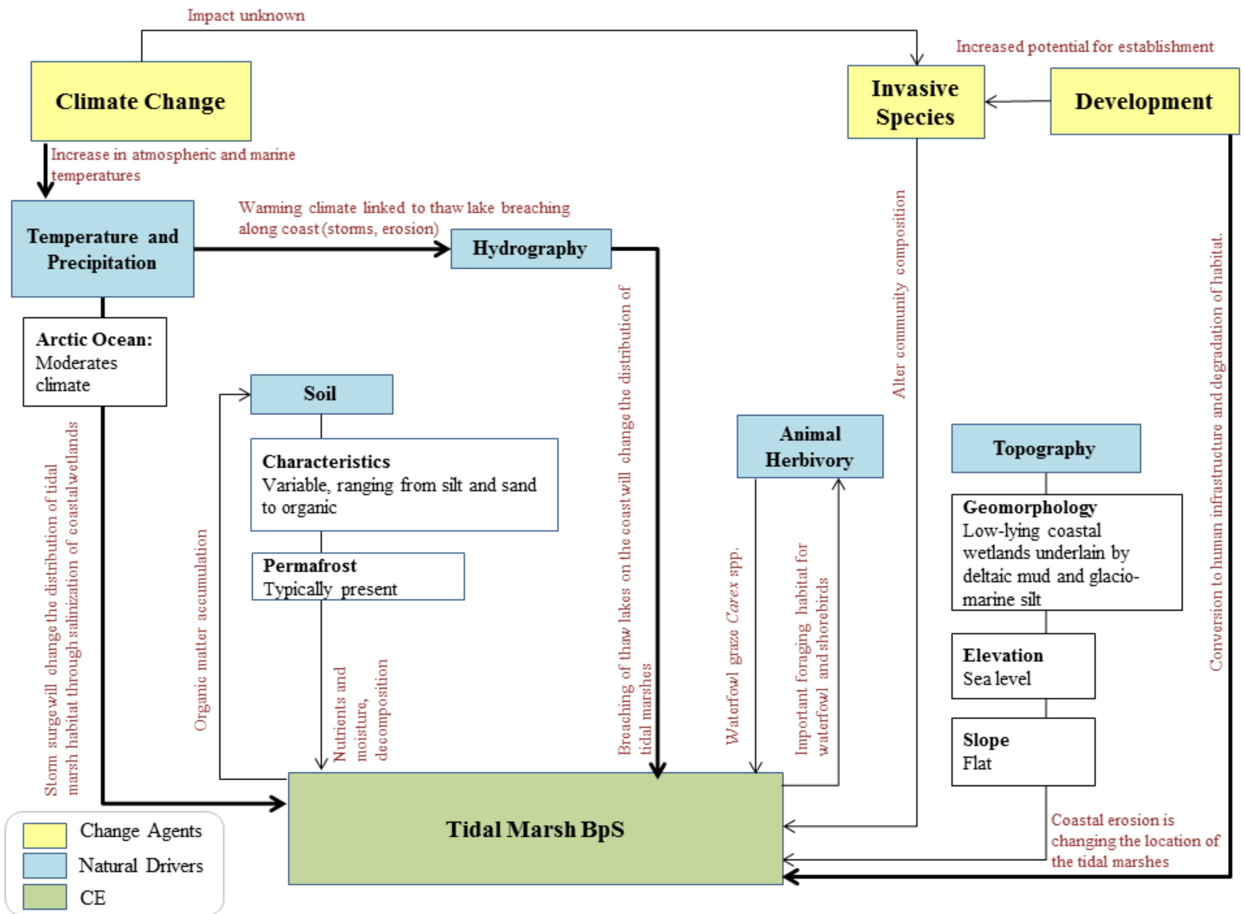


Figure 1. Schematic physiography and vegetation profile of two Arctic Ocean tidal marshes.

Salt-killed tundra occurs where tundra has been inundated by tide water killing most of the tundra species, and tidal species invade. Tidal flooding may occur in any low-lying ecosystem adjacent to the coast. Consequently, salt-killed tundra soils typically preserve a surface organic layer relict from its previous landcover (e.g., tundra or lake). Common plant associations include *Puccinellia phryganodes*, *Carex subspathacea, Carex glareosa,* and *Carex subspathacea-Salix ovalifolia* (Jorgenson et al. 1997, Flint et al. 2008, Boggs et al. [in prep]).

Conceptual Model



Climate Change:

Climate change induced sea level rise, reduction in sea ice cover, and melting or degrading permafrost, in combination, are seriously affecting Arctic tidal marshes. Coastal erosion, which at rates of 1.2 m/year from 1980-2000 (Forbes 2011, Jones et al. 2008, Ping et al. 2011) truncate the seaward expansion of marsh systems. High rates of coastal erosion relate to the combined factors of global sea level rise, increase in ice free days and permafrost degradation. Furthermore, higher relative sea level extends the impacts of storm surges and facilitates the degradation of permafrost. Storm surges 2-3 m above sea level flood coastal and low-lying inland tundra (Taylor 1981); permafrost degradation along the coast allows inundation of nearshore basins, polygonal ground and tussock tundra (Bergman et al. 1977, Jorgenson and Miller 2010). Exposure of tundra vegetation to saltwater weakens or kills the resident species and allows salt-tolerant species to colonize (Bergman et al. 1977, Jorgenson et al. 1994, Kincheloe and Stehn 1991). Similarly, an increase in ice-free days exposes the coastline to coastal erosion, ice rafting and storm surges for a greater period of time, thereby exacerbating the cumulative impacts of these processes.

Invasive Species:

Invasive plant species are rare in this BpS and primarily associated with human development.

Development:

Arctic tidal marshes may be directly impacted by human infrastructure or human use. Due to their landscape position, tidal marshes and mudflats are also highly susceptible to damage from oil spills. The degree of damage from an oil spill to nearshore waters is expected to vary with factors such as degree of tidal influx, tide level, location, ice-coverage, season, and extent and duration of the spill. Sites with high freshwater outflow are expected to be less susceptible (Crow 1977).

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Barrier Island, Spit and Beach

Background

The coast of the Arctic Ocean is dominated by sandy barrier islands, spits, lagoons, beaches, eroding bluffs, deltas, low-lying drained-lake basins that are occasionally flooded by storm surges and tidal marshes. These are dynamic ecosystems that are driven by sea ice, coastal erosion, wind-driven waves, storm surges, sedimentation from rivers and eroding coastal bluffs, and long-shore currents.

We combined barrier islands, spits and beaches into one BpS (i.e. Barrier Island, Spit, and Beach BpS) because of similarities in landform, geomorphic process, and parent material. Definitions of the components within the BpS are as follows: barrier islands are sandy elongate islands separated from the mainland by an estuary or bay, a spit is a sandy elongate continuation of a coastal dune into the ocean (Ritter 1986), and a beach is an expanse of sand or pebbles along the shore including beaches below eroding bluffs. Each is highly dynamic and unstable.

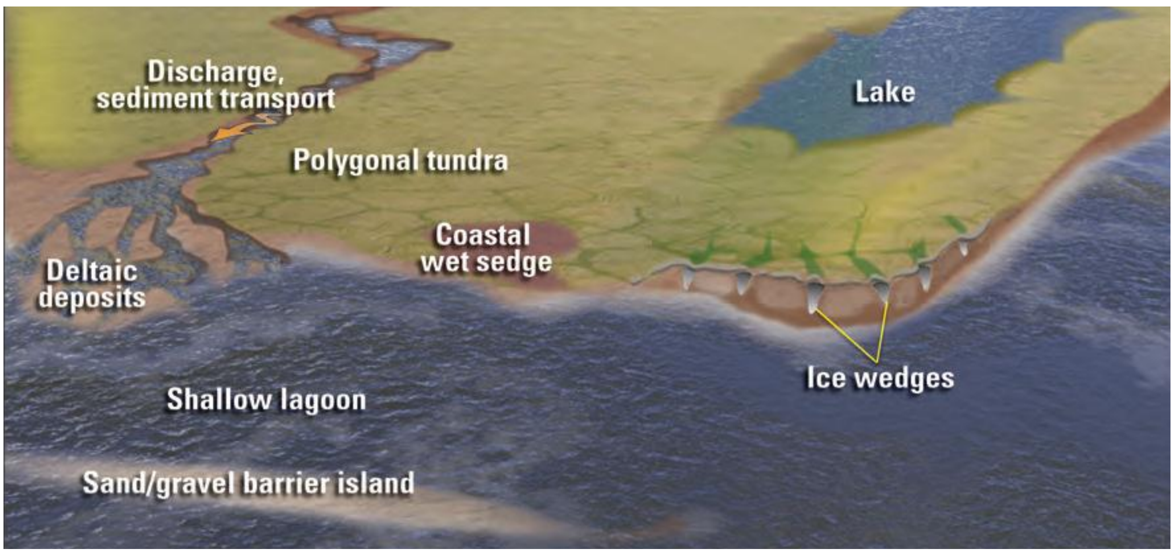


Figure 2. Schematic of arctic coastline landscape. Illustration from Martin et al. (2009). Figure by R. Mitchell/Inkworks for WildREACH from cited sources.

Barrier Islands and Spits

Barrier islands on the Arctic Ocean coastline are thought to be remnants of ancient mainland shores that have eroded and then re-deposited (Hopkins and Hartz 1978, Morack and Rogers 1981). Some retain remnant tundra vegetation underlain by permafrost, but most are shifting sandy islands and spits largely devoid of vegetation.

<u>Environmental Characteristics:</u>

In summer with the melting and removal of the coastal ice, typical coastal processes commence leading to the formations of barrier islands, spits and beaches (Short 1979). The principal geomorphic processes required for the formation of **barrier islands** and **spits** are: deposition of sediment, coasts with low tides, low offshore gradients, and low wave energy. The location and formation of islands and spits depend primarily on the availability of sediment. The main source of sand and silt is thought to be remnants of ancient mainland shores that have eroded and then re-deposited (Hopkins and Hartz 1978, Morack and Rogers 1981). Other sediment sources include major rivers, eroding bluffs, onshore transport of sand from the ocean shelf, and sand transported by wind (Ritter 1986).

The sediment is transported by long-shore currents, waves, and winds and may eventually be stabilized by vegetation. Sea-ice movement (ice-push) may also erode barrier islands and spits, and physically dredge and transport sediment on the beaches (Martin et al. 2009). The long-shore currents, generated by waves that strike beaches obliquely, tend to move sediment parallel to the shoreline for considerable distances. The sediment is deposited when it enters a zone of slack water. Islands and spits thus migrate parallel to the long-shore currents. Waves redistribute the sediment across the beach profile, and wind will erode depositional features and transport the sand downwind. Areas with high wave energy resuspend any silt and transport it to lower energy depositional areas. Consequently, the high-energy side of islands and spits (the seaward side) contains primarily sand and forms beaches and dunes, whereas silt is readily deposited on the low energy-side (the estuary side), forming marshes and tide-flats.

The inlets found between barrier islands and spits serve as avenues for water and sediment movement between the estuary and open ocean. Inlets tend to migrate in the direction of longshore transport as spits or islands erode at one end and deposit sediment at the other.

These islands are typically less than 1 m in elevation but no higher than 3 m (Hopkins and Hartz 1978). Landforms found on barrier islands and spits are strongly affected by overwash (Dolan et al. 1980). During storms, portions of barrier islands and spits often are inundated and subjected to wave action known as overwash. Sand is transported from the beach and deposited further inland on the island or spit. The overwash may only affect the front portion of the landform, or during severe storms can completely wash over these low level islands (Hopkins and Hartz 1978, Ritter 1986).

Historical shoreline data from the 1950's to the present show that the barrier islands studied along the Arctic coast are highly dynamic. The barrier islands have a tendency to migrate westward and landward, (Ravens and Lee 2007, Erikson et al. 2012). The westward migration is in the same direction as sea-ice movement and consistent with the frequent east winds during the summer open water time. New inlets will also form creating additional islands, and these islands may then reform. In subsequent years, the islands may go through more cycles of breakup and reformation (Ravens and Lee 2007).

Beaches

Coastal beaches are common along the Arctic coast including at the base of eroding bluffs. They primarily form by the wave, wind, and long-shore transport of drifting sediment, which is deposited on beach fronts, similar to that described for barrier islands and spits. The dunes and beaches tend to migrate in the direction of the prevailing winds and near-shore currents (Ritter 1986). Ice-push will also erode beaches and physically transport sediment.

Bluff recession:

Beaches also form at the base of eroding bluffs. Bluff recession rates along the eastern section of Alaska's North Slope are some of the worlds highest and the rates are increasing (Jorgenson et al. 2005, Mars and Houseknecht 2007, Aquire 2008, Jones et al. 2009). Various factors influence bluff recession including elevated sea surface temperatures, elevated air temperatures, changes in the active layer depth and permafrost, later freeze-up and earlier break-up of the arctic ice sheet, and frequency and intensity of storm activity. The chief process by which Arctic bluffs erode appears to be by notching near the base of the bluff followed by block failure. A notch develops either from direct wave impact at the base of the bluff or thermal niching. Thermal niching occurs when seawater and higher than normal air temperatures melt the permafrost at the base of the bluff. Block failure then occurs either as a result of exceeded tensile strength, or the presence of an ice wedge back some distance from the bluff face (Erikson et al. 2007, Hoque and Pollard 2008). During a storm surge, strong winds can raise water levels as much as 2 m (Reimnitz and Maurer 1979) and can result in rapid coastline erosion.

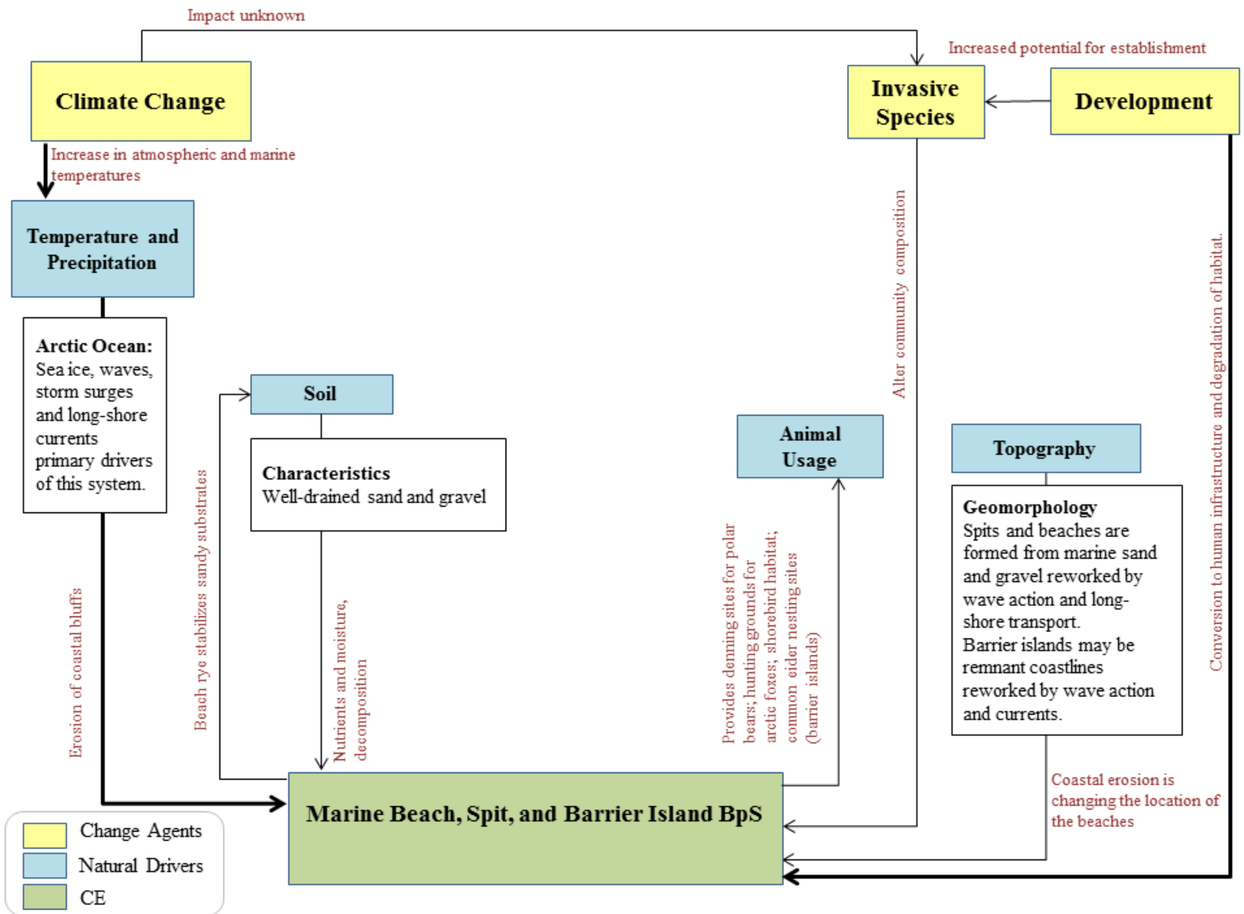
Vegetation Patterns on Barrier Islands, Spits and Beaches:

The vegetation and processes driving vegetation succession are similar for barrier islands, spits and beaches. Each is a sand and/or dune dominated system. Early successional dunes near the ocean receive significant windblown sand, and contain pioneer communities. There is often a rapid readjustment to changing environmental conditions. Newly formed dunes are dependent on vegetation, the size and abundance of sand, and the prevailing wind(s). Obstacles in the wind-run perturb the flow causing a decrease in wind speed leading to sand deposition. Vegetation is often the main obstacle although beach litter is another important obstacle, and acts as a seed and nutrient trap (Carter 1988). Pioneer dune vegetation (primarily *Leymus mollis* [beach rye]) then stabilize the windblown sand. The initial invaders are salt tolerant, although not halophytic, and sand accumulation tolerant. Most dune species reproduce vegetatively because germination is difficult due to the burial by sand and desiccation. Clonal colonies develop rapidly (Carter 1988). Pioneer dunes owe their strength to roots, penetrating 3 to 6 feet and deeper to water (Howard et al. 1977).

Dunes stabilized by vegetation are typically located inland from the earlier stages, have less sand input and have soil development (Carter 1988). The organic and nutrient status develops and supports herbaceous vegetation. Removal of vegetation typically leads to destabilization, blowouts, and erosion of the dunes.

Blowouts are a natural phenomenon in stabilized-vegetated dune fields. They are a primary method of dune movement and elongation, and initiator of primary succession. Blowouts occur when wind exposes bare sand, forming a small hollow on the upwind side of a vegetated dune. The blowout continues to expand, the shape becoming concave with a steep back-slope. Much of the wind-transported sand is deposited on the downwind side of the back-slope, forming delta like or plume like formations. In time, the steep back slope becomes subdued because of mass wasting from sand avalanches and wind erosion. Vegetation then colonizes and stabilizes the blowouts (Carter 1988).

Conceptual Model



Climate Change:

Global modeling studies consistently show the Arctic to be one of the most sensitive regions to global climate changes (Holland et al. 2006, ACIA 2005) as evidenced by the increase of Arctic air temperatures, which are almost twice the global average rate over the past 50 to 100 years, of about 4 °C (Chapman and Walsh 2007, IPCC 2007). This warming trend has been accompanied by an extension of the open water season, which typically extends from mid-June through early October, and a shrinking of the perennial ice sheet covering the North Pole and much of the Arctic. Satellite images show that the perennial ice sheet has shrunk by more than 30 percent since 1979 and reached a historical minimum in 2007.

This reduction in sea ice has resulted in an increase in wave energy, and increase in storm surges related to increased fetch across the open Arctic Ocean. Sea level is also currently rising at 3 mm/yr and projected to rise 0.5–1.0 m by the end of the century.

Barrier Islands and Spits: The following is an assessment of the influence of climate change on barrier islands and spits by Martin et al. (2009). “Preliminary evidence suggests that the Beaufort Sea barrier island system may be disintegrating. For example, Narwhal Island, which is east of Prudhoe Bay, has greatly diminished in surface area since 1955, and the migration rate from 1990–2007 (24 m/yr) greatly exceeds that from 1955–1990 (5 m/yr). Total surface area of barrier islands in the central Beaufort Sea (Colville River to Point Thomson) has decreased approximately 4% from the 1940s to the 2000s, and the rate of change is greater during the period since 1980 (Gibbs et al. 2008). A longer period of open water and increased occurrence of larger waves is at least partially responsible for this acceleration.

Ice-push events require the coincidence of strong onshore winds and a high density of broken ice, and this may occur less frequently as sea ice retreats farther offshore in summer. Warming ocean temperatures also may play a role, however, as even the constructional islands may be partially composed of ice-bonded sediments (Morack and Rogers 1981), which inhibit longshore sediment transport (Thomas Ravens and William Lee, University of Alaska Anchorage, personal communication). These trends suggest that the deterioration or disappearance of the existing system of barrier islands is possible over a relatively short period."

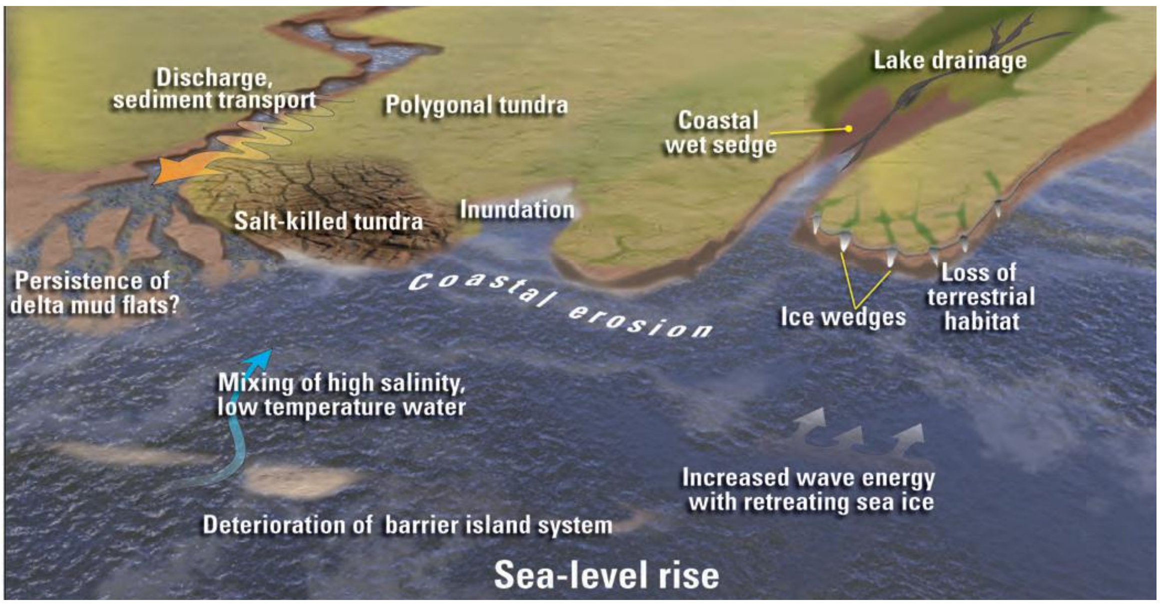


Figure 3. Schematic of future arctic coastline landscape. The projected landscape illustrates elements likely to change as a result of climate warming. Figure by R. Mitchell/Inkworks for WildREACH from cited sources.

Bluff recession: The warming climate and sea-level rise is strongly influencing rates of coastal retreat (Jorgenson et al. 2005, Mars and Houseknecht 2007, Aquire 2008, Jones et al. 2009). The impact of the coastal retreat is losses in freshwater and terrestrial wildlife habitats, disappearing cultural sites, and adversely impacting coastal villages and towns, and the oil industry infrastructure. The increase in storm heights, accompanied by sea-level rise, has also resulted in flooding and salinization of low-lying terrain.

<u>Invasive Species:</u>

Invasive plant species are rare in this BpS and primarily associated with human development.

<u>Development:</u>

Due to their landscape position, barrier islands are highly susceptible to damage from oil spills and human use. Degree of damage from an oil spill to near-shore waters is expected to vary with factors such as degree of tidal influx, tide level, location, season and extent and duration of the spill. Off-road-vehicle use also occurs on some of the islands.

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Coastal Plain Wetland

Background

The Coastal Plain Wetland BpS is characterized by basin wetlands and low-centered polygonal tundra. This BpS forms the matrix landscape type between the oriented thaw lakes that cover much of the northern portion of the Coastal Plain north of the sand sheet. We have described sand sheet wetlands as a separate BpS because we hypothesize that the effect of climate warming on wetlands and surface water could differ between these two regions. Soils are saturated, and standing water is usually present during the growing season. A thick organic horizon typically occurs over silty deposits of marine, glacial or alluvial origin. Ice-rich permafrost occurs within 1 m of the surface (Jorgenson and Grunblat 2013). Ice wedges are visible on the landscape as raised ridges around low-lying polygon centers.

Distribution:

NSSI landcover classes in the Coastal Plain Wetland BpS include: FWM: *Arctophila fulva*, FWM: *Carex aquatilis*, and Wet sedge. Its distribution is limited to the coastal plain physiographic region excluding the Arctic Sandy Lowland ecological landscape.

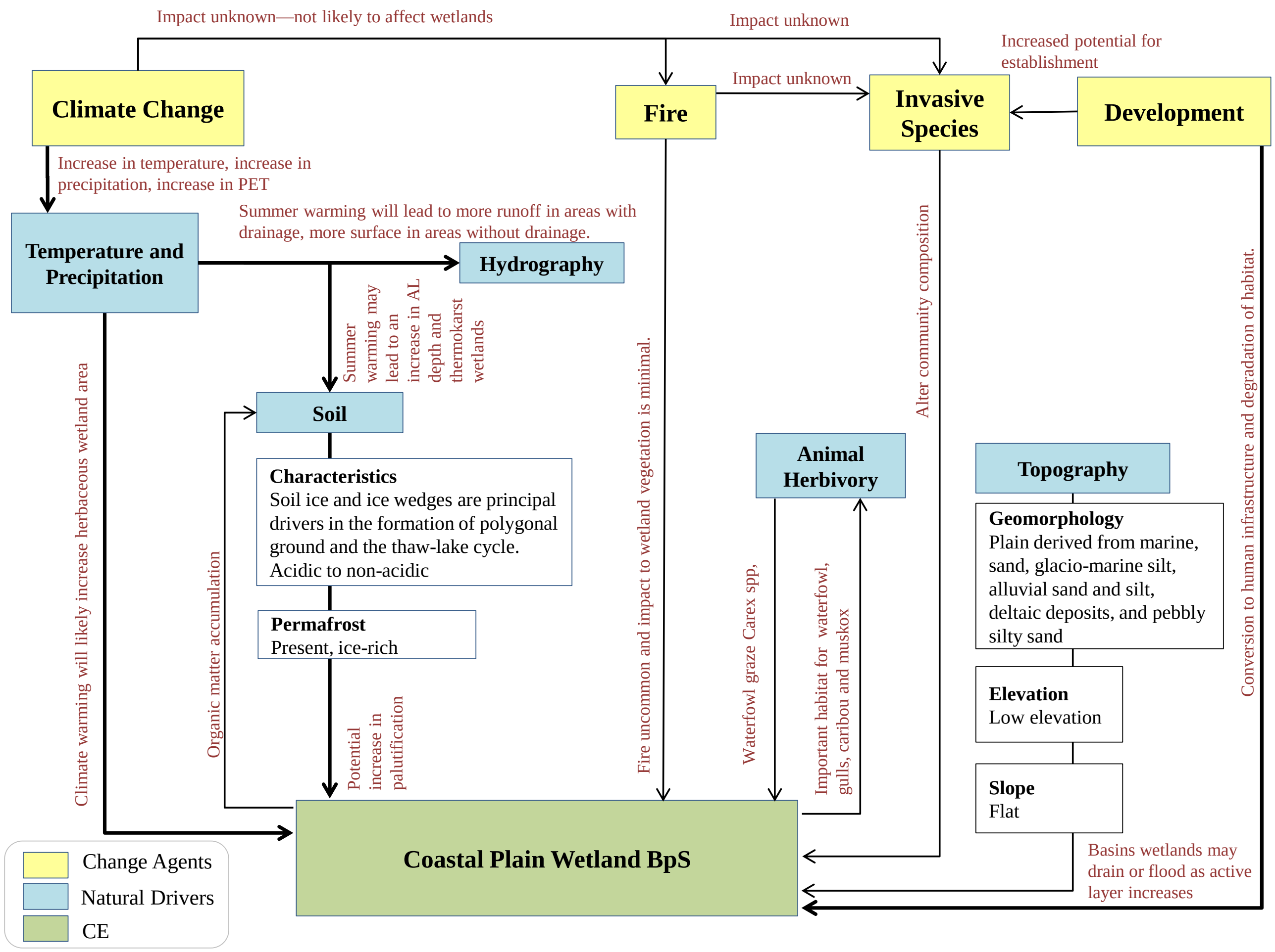
Vegetation:

Wet sedge meadows are the dominant vegetation of basin wetlands. The most common species is *Carex aquatilis*; other diagnostic species include *Carex rotundata, Eriophorum chamissonis,* and *Eriophorum angustifolium*. *Carex chordorrhiza* is characteristic of very wet floating sedge peat habitats. Shrubs occur on raised microsites, such as polygon ridges. Common species include *Betula nana, Salix fuscescens, Vaccinium uliginosum,* and *Andromeda polifolia*. Mosses of the genera *Drepanocladus* and *Scorpidium* may be common on circum-neutral sites with standing water; *Sphagnum* spp. may be common on more acidic sites. Fresh marsh communities are found in deeper water at the margins of ponds and lakes and in thermokarst pits. *Arctophila fulva* is characteristically dominant, other species of these communities may include *Hippuris vulgaris* and *Utricularia vulgaris*. Aquatic mosses, including *Calliergon* spp. may be present, sometime in mats floating on the water surface.

Wildlife habitat:

Coastal Plain Wetland BpS provides important habitat for water birds, gulls, caribou, and muskox.

Conceptual Model



Climate Change

The ice-rich permafrost in this Bps is sensitive to climate warming because ice wedges are typically in contact with the active layer, 30–40 cm below the soil surface. Ice-rich permafrost is also susceptible to surface subsidence as the active layer becomes deeper. Observed degradation of ice wedge polygons on the coastal plain west of the Coleville River Delta has led to an increase in thermokarst pits and surface water area (Jorgenson et al. 2006). In areas without drainage, such as basins and flat topographic features, permafrost degradation could result in an overall increase in wetland area. Warmer temperatures could also increase rates of paludification of wetlands, which could lead to a shift from freshwater marsh habitat to lower productivity acidic bogs (Szumigalski and Bayley 1997, Thormann and Bayley 1997). Conversely, in areas connected to a drainage system, degradation of polygons could create troughs between polygon centers and new drainage networks could form leading to a pattern of mesic polygons surrounded by wetlands.

Warmer and drier summer conditions could lead to a negative water balance, which could lead to desiccation of shallow ponds and wet sedge meadows (Smol and Douglas 2007). In basin topography, the balance between water added to the system through precipitation and themokarst and the water lost through evaporation and evapotranspiration will determine whether the net effect is that of wetting or drying of the landscape. The combination of surface subsidence and lack of drainage networks will likely lead to increased wetland area in this BpS.

Fire

Fire is uncommon on the Coastal Plain. It is not likely that fire will impact Coastal Plain Wetlands.

Invasive Species

Currently no invasive plant species are known to occur in Coastal Plain Wetlands. Species such as *Elodea* may be able to survive if introduced.

Development

Infrastructure development will result in direct loss of habitat, and also have indirect effects on adjacent habitat. The wetland environment is susceptible to contamination oil spills, particularly when the ground is snow-free.

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Coastal Plain Moist tundra

Background

The Coastal Plain Moist Tundra BpS is characterized by moist polygonal tundra with little topographic relief. This BpS includes both high-centered and flat-topped polygonal ground and forms the matrix between coastal plain basin wetland topography. We have excluded the moist tundra on the sand sheet from this BpS because we hypothesize that the effect of climate warming on active layer, ice wedge stability, vegetation, and surface water will differ between these two regions. Soils are poorly drained and formed on silty deposits of marine, glacial or alluvial origin. Ice-rich permafrost occurs within 1 m of the surface (Jorgenson and Grunblat 2013).

Distribution:

NSSI landcover classes in the Coastal Plain Moist Tundra BpS include: Tussock Tundra and Tussock Shrub Tundra, Mesic Sedge-Dwarf Shrub Tundra, Mesic Herbaceous, and Birch Ericaceous Low Shrub. Its distribution is limited to the coastal plain physiographic region excluding the Arctic Sandy Lowland ecological landscape.

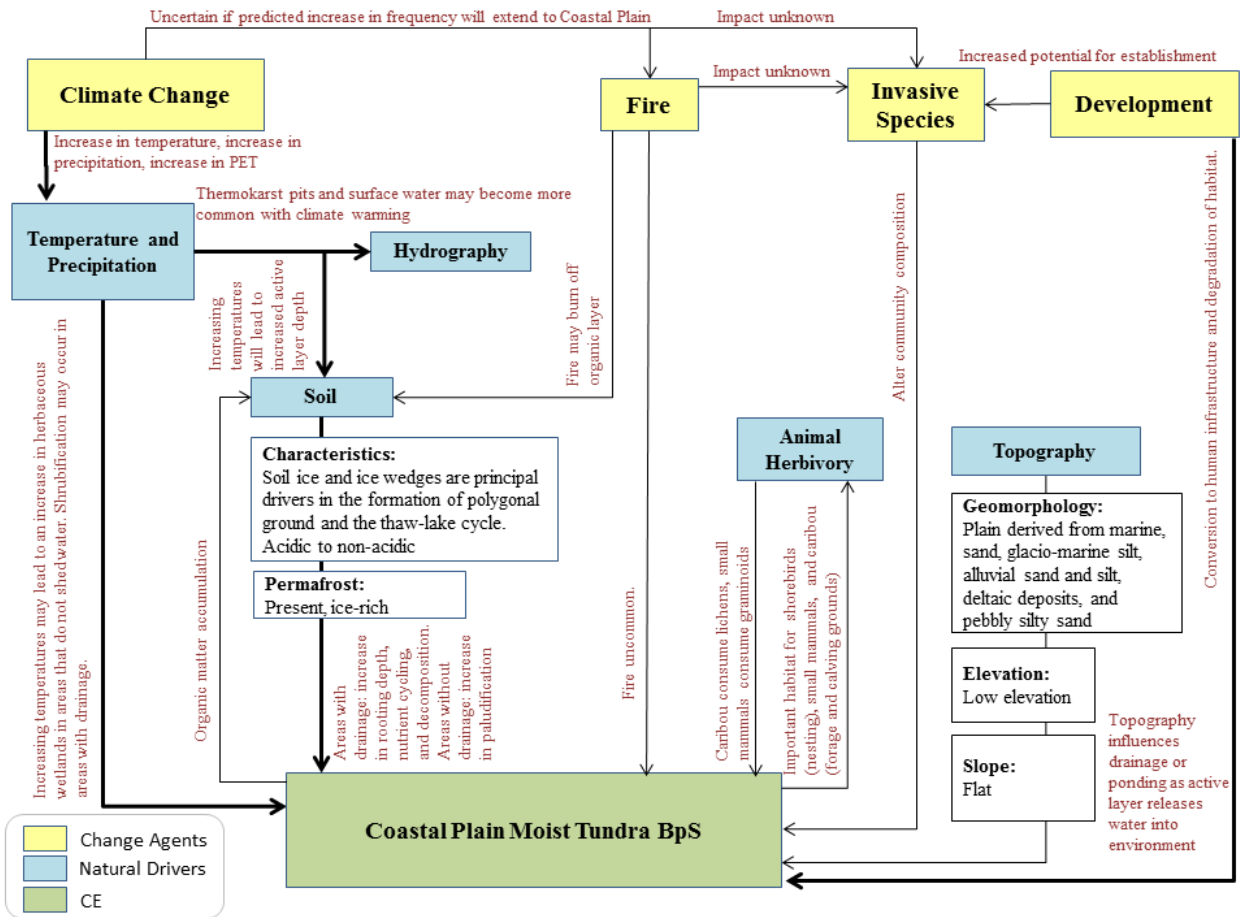
Vegetation:

Tussock forming sedges *Eriophorum vaginatum* or *Carex lugens* are the dominant species and usually have a combined cover of at least 40%. Shrub cover is variable, but generally exceeds 25%. *Salix pulchra, Ledum palustre* ssp. *decumbens, Cassiope tetragona, Betula nana,* and *Vaccinium vitis-idaea* are the most common shrubs. Common mosses include *Hylocomium splendens, Aulacomnium* spp., *Tomentypnum nitens, Dicranum* spp., *Sphagnum* spp. Lichens are consistently present with low canopy cover; common species include *Peltigera* spp., *Flavocetraria* spp., *Cladina* spp., and *Thamnolia vermicularis.*

Wildlife habitat:

The Coastal Plain Moist Tundra BpS provides important foraging and calving habitat for caribou, nesting habitat for shorebirds, forage, shelter, and breeding habitat for voles, shrews, lemmings, and ground squirrels.

Conceptual Model



Climate Change:

This landscape is characterized by ice-rich permafrost and polygonal features. Ice wedges are in direct contact with the active layer, and thus will respond rapidly to changes in temperature. Increasing summer temperatures will likely lead to ice wedge degradation and an increase in thermokarst pits resulting in an increase in surface water. This process has been documented in the polygonal tundra near the Colville River Delta (Jorgenson et al. 2006). If this trend continues, we expect a shift from moist tundra to open water and herbaceous wetlands in areas that do not shed excess water. Regions that shed water may develop drainage networks and deepening polygon troughs with drier polygon centers. Tundra in these regions will likely remain moist and may exhibit an increase in shrub height and cover (Sturm et al. 2001, Wahren et al 2005, Tape et al. 2006). This is similar to the impact predicted for the Sand Sheet Moist Tundra and Foothills Tussock Tundra BpS.

Fire:

Fire is uncommon on the Coastal Plain. It is unclear if the predicted increase in fire frequency will affect this region.

Invasive Species:

The distribution of invasive plant species is currently limited within the project area. Non-native plant species have only been documented in disturbed habitat such as towns and airstrips. Development of infrastructure will increase the potential for establishment in disturbed areas.

Development:

Infrastructure development will result in direct loss of habitat, and can also have indirect impacts on adjacent habitat. New development will increase the potential for aerial transport and deposition of fine sediment near roads, airstrips, and towns, and also increase the potential for sediment transport into waterways through erosion. Ice roads and winter trails can damage moist tundra vegetation, particularly tussock vegetation (Guyer and Keating 2005, Felix and Raynolds 1989). Compression of tussock and bryophytes can lead to changes in active layer depth and can result in a shift from moist tundra to wet sedge vegetation. These changes may lead to changes in drainage networks that may affect adjacent vegetation.

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Sand Sheet Wetland

Background

Large deposits of Pleistocene sands cover much of the arctic coastal plain east of the Colville River. Sand sheet wetlands occur where saturation with water is the dominant factor in determining the nature of soil development and communities living in the area are referred to as sand sheet wetlands. These wetlands include lowland areas of drained lake basins and cutoff meanders. Much of the sand sheet wetlands have polygonal surface patterns and an organic soil layer aging from a few thousand to at least 9,500 years. The size, shape and orientation of polygon features vary with the age of the terrain and boundary features such as lakeshores or point bars. Polygons of older terrain aging between 4,000 to 5,000 years are generally larger in size and are more ovoid in shape as compared with those of less common younger terrain (Everett 1979). The sand sheet wetlands region differs from nearby regions of loess or glacio-marine soils. Sand sheet ground-ice volumes are lower as compared with loess derived soils. Lakes upon the sand sheet are less numerous, not as strongly oriented to the northwest, and have more irregular shorelines. Sand sheet rivers are interconnected with lakes, are often sluggish, and show an extreme, often regular meander pattern as compared with the more eastern rivers associated with silt terrain, which are braided and build deltas in the Arctic Ocean. The large rivers also have more deeply incised channels. Permafrost-related surface features such as pingos, ice-wedge polygons, oriented lakes, peat ridges, and frost boils are less common and less pronounced on the sand sheet.

Distribution:

Cold-climate dune fields in North America, Europe and Asia are estimated to cover an area of over 100,000 km^2 (Koster 1988). Large regions of sandy tundra in occur on the Yamal and Gydan peninsulas, Russia, and in coastal river deltas and glaciofluvial outwash deposits throughout the arctic. The large sand sheet on the Arctic Coastal Plain of Alaska lies between the Meade and Colville Rivers north of the Brooks Range Foothills.

Vegetation:

Spatial patterns of plant communities reflect microtopographic relief caused by geomorphic processes, including ice-wedge activity, seasonal thaw depths, thaw-lake processes, river meandering and erosion and deposition of sands. Moisture and permafrost appear to be the primary controls on vegetation.

Fresh grass marshes with *Arctophila fulva* are common in ponds, slow flowing streams, margins of lakes and thermokarst pits. Water depth ranges from seasonally flooded to up to two meters. Other plants that may occur in *Arctophila fulva* habitats include *Hippuris vulgaris*, *Utricularia vulgaris,* and *Ranunculus pallasii.* Mosses of submerged or floating habitats, including *Calliergon richardsonii, Pseudocalliergon brevifolium, Scorpidium revolvens, Scorpidium scorpioides, Sphagnum orientale, Straminergon stramineum, Warnstorfia sarmentosa,* and *Warnstorfia tundrae* are commonly found in fresh grass marshes.

Wet sedge meadows occur in drained lake basins, lake margins, depressions, and on level to gently sloping flood plains and terraces. These communities are commonly dominated by either *Carex aquatilis* or *Eriophorum angustifolium*. Woody species are usually absent, though sometimes prostrate willows (e.g., *Salix ovalifolia*, *S. pulchra, S. richardsonii*) are important. Bryophytes composition may include the following species: *Cinclidium* spp*., Dicranum spadiceum, Meesia uliginosa, Paludella squarrosa, Polytrichum swartzii, Pseudocalliergon turgescens, Sphagnum* spp*., Straminergon stramineum, Warnstorfia* spp*., Lophozia* spp*., Scapania* spp*.,* and *Aneura pinguis. Sphagnum* is usually of low cover but may codominate at some sites. *Scorpidum scorpioides* is found circumneutral substrates, while *Sphagnum* is often indicative of acidic sites. Presence of *Carex chordorrhiza* is characteristic of very wet floating sedge peats (Viereck 1992).

Some wet poorly drained sites with standing water (e.g., oxbow lakes, lake and pond margins, kettles and other depressions, and very wet polygon pans) may have high cover of forbs such as *Petasites frigidus*. Other wet sedge meadows near the arctic coast (Viereck 1992) Grasses such as *Dupontia fisheri* or *Alopecuris alpinus* may codominate.

Willow sedge shrub tundra communities occur on pond margins, streambanks, low-center polygons, drained lake basins, and sometimes fens of poorly drained lowlands. These communities have 25 to 75 percent cover of shrubs, primarily willows, especially *Salix pulchra*. *Carex aquatilis* typically dominates the understory, though other sedges such as *C. vaginata* and *C. bigelowii* are sometimes dominant. Other vascular plants commonly present include *Salix arctica* and *S. reticulata.* Nonsphagnaceous mosses, commonly including *Tomenthypnum nitens, Drepanocladus* spp., and *Campylium stellatum,* often are abundant. Lichens are scarce. Many stands may be fairly stable. Drying trends may produce changes toward shrub-tussock tundra. Increased moisture may cause a decrease in willows and shift toward wet sedge meadow.

Strangmoor, or string bogs, consists of alternating low bog ridges and wet sedge depressions. These *Sphagnum*-dominated fens occur in drained lake basins, usually on the outer side of marsh stands that are located near the basin center. The bog or fen ridges undulate and are oriented at right angles to drainage and solifluction movement (Drury 1956). *Carex aquatilis, Salix pulchra,* and minerotrophic species of *Sphagna* are characteristic of strangmoor.

Environmental Characteristics:
Major aspects of the sand sheet landscape were produced by aperiodic events of sand dune formation associated with shifts in meander pattern of the Colville River. The ancient dunes control distribution and form of larger lakes in the region. Lakes over most of the coastal plain sand sheet formed as lowland basins and depressions of the sand sheet dune surface filled with of water during the beginning of the Holocene. After initial flooding, lake levels fluctuated with changes in precipitation, evaporation and drainage. Wave action erodes and expands shorelines and redistributes lake sediments; with silt and fine organic materials accumulating in the deepest parts of the lakes.

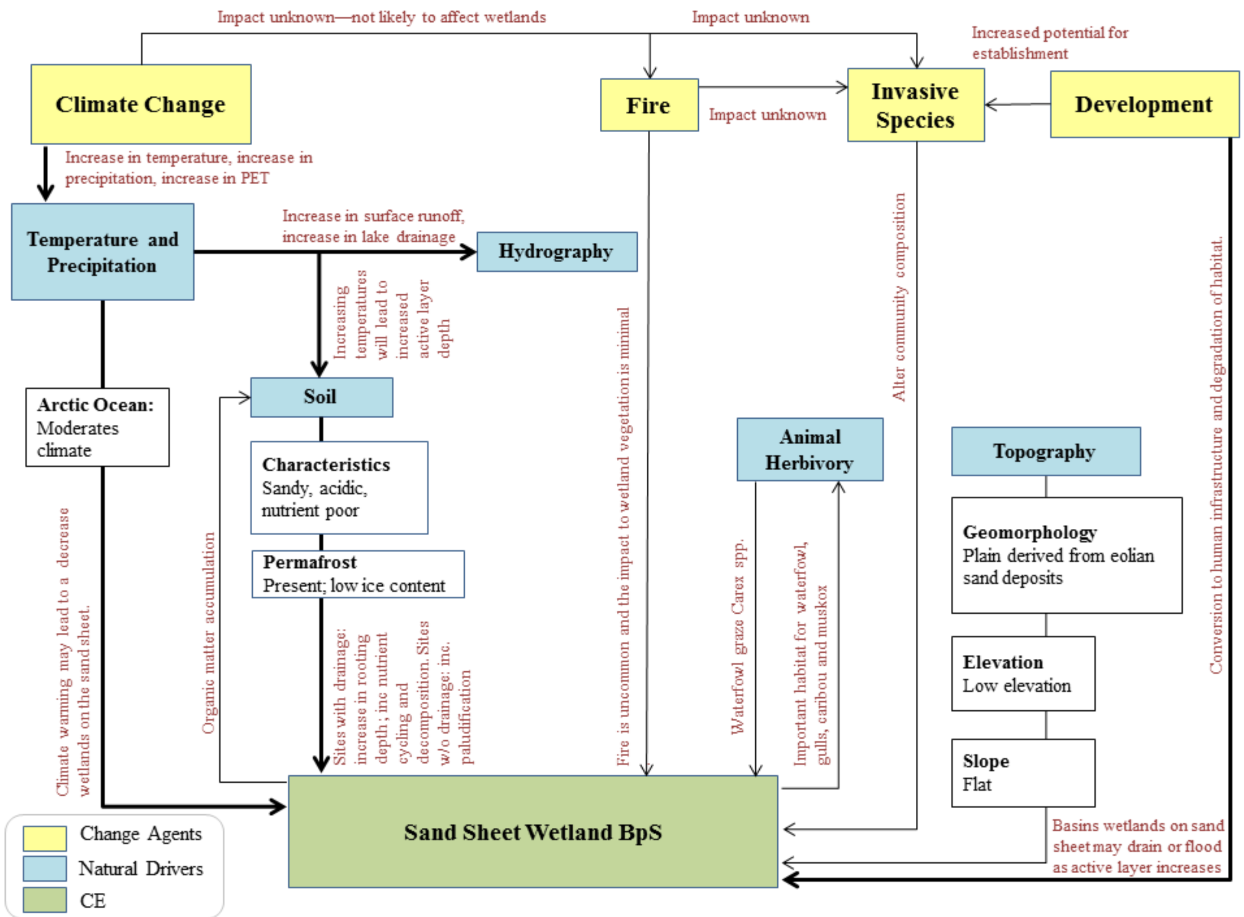
Development and expansion of water flow networks that developed in the early Holocene facilitated drainage of some of the larger lakes. Peat core samples from drained basins in Barrow and northeast part of the National Petroleum Reserve suggest that drainage was most active over 1000–5000 years B.P. (Jorgenson and Shur 2007). Exposed sediments of drained lakes are subject to permafrost aggradation. Density and volume of ground ice in newly exposed sediments varies widely in relation to soil properties. Little ice aggrades in sandy sediments along the lake margins. In contrast, ice segregation and ice wedge formation is prevalent in organic silt sediments of the lowest parts of the lakebed. Once a basin is drained, ice heaving uplifts the ice-rich center of the basin. Small ponds form as water fills in lower depressions of the lower-lying sandy margins along the edge of the drained basin. Many sand sheet lakes, therefore, are not of thermokarst origin but formed through infilling of depressions within basins during flooding events (Jorgenson and Shur 2007).

Through repeated cracking, filling, and freezing; ice wedges of drained basins grow in width and depth. The pressure of the growing subterranean ice wedges displaces soil upward, resulting in large, often rectangular, low center polygons. As more ice wedges arise, the polygonal pattern increases and the polygons divide into smaller units. In lower, wetter areas, wind-blown water in the center of the polygons erodes the rims between the polygons, producing a small pond. These true thermokarst thaw ponds become deeper and larger as wind erodes the shoreline.

Sediment and peat from the surrounding tundra wash into lakes and infilled ponds, covering and insulating the ice wedges beneath the lakebed. Small streams erode through low shorelines of the lake, effectively tapping and draining water from the lake. Following drainage, the barren lakebed sediments appear as large, relatively low, high-center polygons with rather wide troughs above ice-wedges. These true thaw lakes that develop from the melting of ice-rich fine-grained soils are constrained to centers of old basins where silts and organic material accumulated**.**

Over time, paludification occurs in ponds with accretion of sedge peats and benthic algae mats. Long term accumulation of peat creates surfaces conditions favorable for plant growth and vegetation slowly encroaches toward the pond center. A shift from grass or sedge marsh to wet sedge meadow tundra occurs along the pond margin. These minerotrophic wetlands communities may gradually develop into acidic bogs with surface vegetation raised above the influence of the groundwater (Zobel 1988). In general, the fen to bog transition occurs in two steps: (1) the acidification of the fen by *Sphagnum* species and (2) peat accumulation and isolation from the influence of water inflow from the surrounding mineral soil. Allogenic processes, including those affecting hydrology and the water table, are likely integral in inducing the fen-bog transition and presumably these processes can also reverse peatland succession (Magyari et al. 2001, Hughes and Dumayne-Peaty 2002). Flooding apparently prevents the establishment of bog *Sphagnum* (Granath et al. 2010) and therefore acidification. Conversion of shallow water and sedge tundra on the Arctic Coastal Plain to acidic bog habitats would have profound ecological implications, given that acidification impedes nutrient availability, lowers productivity, and creates favorable conditions for slower-growing sedges and heath shrubs (Szumigalski and Bayley 1997, Thormann and Bayley 1997).

Conceptual Model



Climate Change:

Understanding the interaction between permafrost and plant communities of sand sheet wetlands is the key to predicting their linked response to climate change. Changes to the active layer induced by climate change are likely to be affected by concurrent changes to the vegetation and soils. The details of the linkages between climate, vegetation, soils, and the active layer are not well understood (Benninghoff 1966, Klene et al., 2001, Shiklomanov and Nelson 2002, 2003, Vasiliev et al., 2003). In general vegetation shades the soils and provides insulation that reduces summer heat flux. Moss and organic matter in the soil increase the water holding capacity affecting the hydrological properties. Thick moss carpets and organic soil horizons decrease active layer thickness, consequently decreasing the depth to which water is able to drain because of the presence of permafrost (Kane 1997). This process of waterlogging, or *paludification*, is thought to be the driving mechanism behind long-term vegetation succession and changes in the active layer thickness in the Low Arctic (Walker and Walker 1996, Mann et al. 2002).

Fire:

The natural fire regime in the arctic is largely unknown. Historically tundra fires rare on the North Slope. Assessment of vegetation succession along a century-scale chronosequence of tundra fire disturbances supports the hypothesis that tundra fires facilitate invasion of tundra by shrubs. Degradation of ice-rich permafrost was also evident at the fire sites and likely influenced changes in tundra vegetation following fire. Identification of previously unrecognized tundra fires that occurred in arctic Alaska may better understanding disturbance regimes and carbon cycling in the region (Jones et al. 2013).

Invasive Species:

Invasive plant species in sand sheet wetlands are rare and primarily associated with human development.

Development:

Infrastructure development will result in direct loss of habitat, and also have indirect effects on adjacent habitat. Mechanical disturbances result in compression of vegetation and soil, melting of buried ice, thermokarst subsidence, thermal erosion, mechanical erosion resulted in long lasting inhibiting influences on sand sheet vegetation at Fish Creek (Lawson 1978).

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Sand Sheet Moist Tundra

Background

Much of Alaska's Arctic Coastal Plain is covered by fine-grained soils associated with windblown loess deposits (Walker 2003**)**. An exception is the large deposit of quaternary aeolian sands that lies between the Meade and Colville Rivers. The ancient dune formations control the distribution and form of larger lakes (Everett 1979). Within the region, sand sheet moist tundra occurs in areas where drainage prevents perpetual soil saturation.

The sand sheet moist tundra landscape is mostly flat or gently sloped. Major features of include longitudinal and parabolic dunes, series of symmetrical and parallel ridges that were formed by aperiodic events of sand movement. Sandstorm events are associated with shifts in meander pattern of Meade River, the erosion of lake bluffs or sand basins of drained lakes. The sand sheet wetlands region differs from nearby regions of loess or glacio-marine soils. Sand sheet ground-ice volumes are lower as compared with loess derived soils. Lakes upon the sand sheet are less numerous, not as strongly oriented to the northwest, and have more irregular shorelines. Sand sheet rivers are interconnected with lakes, are often sluggish, and show an extreme, often regular meander pattern as compared with the more eastern rivers associated with silt terrain, which are braided and build deltas in the Arctic Ocean. The large rivers also have more deeply incised channels. Permafrost-related surface features such as pingos, ice-wedge polygons, oriented lakes, peat ridges, and frost boils are less common and less pronounced on the sand sheet.

Sands of the oldest and most common deposits are stabilized by vegetation. Gentle slopes ascending from drained lake basins to ancient ridges are generally unpatterned (i.e., nonpolygonal terrain). These mesic surfaces show least amount of thawing in summer (Everett 1980).

Distribution:

Cold-climate dune fields in North America, Europe and Asia are estimated to cover an area of over 100,000 km^2 (Koster 1988). Other large regions of sandy tundra in occur on the Yamal and Gydan peninsulas, Russia, and in coastal river deltas and glaciofluvial outwash deposits throughout the arctic. The large sand sheet on the arctic coastal plain of Alaska lies between the Meade and Colville Rivers north of the Brooks Range Foothills.

Partly stabilized dune fields in central and northern Alaska cover an area of more than 30,000 km^2 (Pewe 1975, Hopkins 1982). Active inland dunes occur as isolated features in northwest Alaska, western Canada, and Siberia.

Vegetation:

Spatial patterns of plant communities reflect microtopographic relief caused by geomorphic processes, including ice-wedge activity, seasonal thaw depths, thaw-lake processes, river meandering and erosion and deposition of sands. Moisture and permafrost appear to be the primary controls on vegetation**.** Moist sand sheet tundra is predominantly acidic and tends to have high abundance of low shrubs including *Betula nana, Ledum decumbens* ssp. *palustre,* and *Salix pulchra*. In contrast, non-acidic loess tundra have usually have more flowering forbs and standing dead grasses, relatively fewer erect deciduous shrubs, and sedges of the genus *Carex* (Walker et al. 2003).

Moist lowland areas that are not patterned support open communities which are often dominated by *Salix pulchra* and/or *Carex aquatilis. Salix richardsonii* and *Carex bigelowii* may also be abundant. Some stands include *Betula nana, Rubus chamaemorus,* and *Sphagnum* spp. as important components. This vegetation type covers large areas in the meander belt on floodplains, drained lake basins, and stabilized dunes.

Extensive areas on poorly drained flats, plateaus, benches and gentle slopes are dominated by *Eriophorum vaginatum*. In some stands *Carex bigelowii* is also an important tussock forming sedge. Low shrubs characteristically include shrubs *Betula nana, Ledum decumbens, Vaccinium vitis-idaea, V. uliginosum,* and *Empetrum nigrum, Cassiope tetragona* and *Salix pulchra.* Forbs include *Rubus chamaemorus, Petasites frigidus, Arnica lessingii, Pedicularis sudetica, Tephroseris atropurpurea* ssp. *frigida.* Nonvascular plants commonly found in and between the tussocks include mosses *Dicranum elongatum, Aulacomnium turgidum, Polytrichum hyperboreum, Tomentypnum nitens*, *Sphagnum* spp., lichens *Cladina* spp., *Dactylina arctica, Flavocetraria nivalis, Flavocetraria cucullata, Thamnolia vermicularis*, *Nephroma arcticum,* and liverworts *Anastrophyllum minutum, Blepharostoma trichophylla,* and *Calypogeia sphagnicola*.

Active inland dunes occur in areas of contemporary erosion and deposition of sand. Willows and graminoids make up most of the sparse vegetation cover. Open sands of active dunes are colonized by *Leymus mollis*. Dead leaves of *Leymus* accumulate at the base of them stem and radiate out from it, providing increased cover along the soil surface. *Carex obtusata* also plays an important role. Growing from rhizomes in straight rows, shoots of *C. obtusata* catch windblown material, including fragments of lichens (e.g., *Alectoria nigrescens*) and mosses (e.g., *Racomitrium lanuginosum*), that form colonies between shoots of the sedge. As sands are stabilized, other plant species colonize the dunes. Graminoids of active dunes include *Dupontia fisheri*, *Carex obtusata, Festuca rubra, Bromus pumpellianus. Kobresia sibirica,* and *Trisetum spicatum.* Willow shrubs found on active dunes include *Salix alaxensis, S. glauca, S. ovalifolia, S. niphoclada, Salix pulchra*, and *S. lanata*.

Interdune slacks feature wetland habitats with species such as *Equisetum arvense*, *Carex aquatilis, Carex maritima,* and *Juncus arcticus* ssp. *alaskanus*, *Dupontia fisheri*. Mosses found in moist sand dunes include species of *Barbula, Brachythecium, Campylium, Encalypta, Didymodon, Distichium, Ditrichum, Hypnum, Orthotrichum,* and *Tortula*.

Autogenic succession of well drained dunes and bluffs culminates in mats of vegetation characterized by dwarf shrubs, cushion plants, and fruticose lichens. *Dryas integrifolia* may be locally abundant in many different habitats. Other dwarf shrubs that may also be present include *Salix reticulata, Salix phlebophylla, Empetrum nigrum*, *Arctous rubra*, *Diapensia lapponica* and other ericaceous shrubs (*Vaccinium vitis- idaea,* and *Ledum palustre* ssp. *decumbens*). Graminoids such as *Adoxanthum monticola*, and *Carex bigelowii*, *Festuca rubra*, and *Luzula confusa* may reach relatively high coverage among vascular plants. Bryophyte or lichen-dominated communities with mosses *Racomitrium* *lanuginosum*, and *Polytrichum hyperboreum, Encaypta rhaptocarpa, Distichium capillaceum* are also found on stabilized dunes. Lichens are important in these communities on old surfaces, including: *Alectoria nigricans, Alectoria ochroleuca, Bryocaulon divergens, Asahinea chrysantha, Thamnolia vermicularis,* and *Dactylina arctica*. The well drained sandy surfaces of sand sheet region characteristically have high diversity of forbs and may harbor rare species such as *Draba pauciflora, Erigeron ochroleucus, Erigeron porsildii, Koeleria asiatica, Mertensia drummondii, Poa hartzii* ssp. *alaskana, Puccinellia vahliana, Symphyotrichum pygmaeum*. In addition plant species which are widely disjunct from their respective known distributions are known from active inland dunes. Modern active dune fields are strongly linked by shared floristic elements, Quaternary origins, and geomorphic landforms and processes.

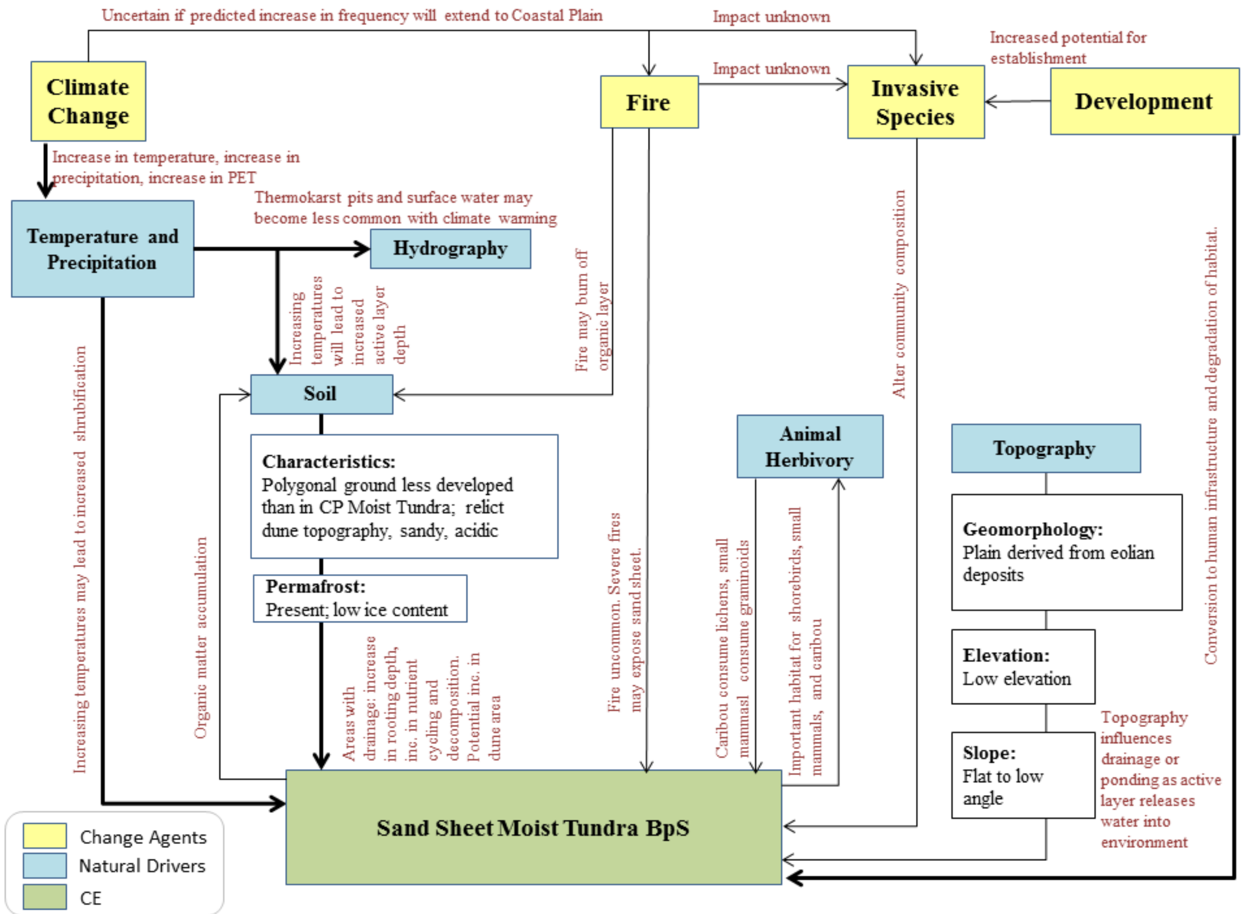
Environmental Characteristics:

The soils of active and temporarily stabilized sand dunes or dune remnants generally consists of unconsolidated sand deposits that show little evidence of soil forming processes and have no horizon differentiation. Nearly pure sand that contains little clay, these soils are of low fertility. Due to low production and rapid turnover rates of organic material, these soils have low organic carbon and low cation exchange capacities. Total nitrogen is low and occurs in significant quantities only at soil surface.

In these moderately well drained soils August thaw reaches between 60 and 115 cm and the water table is never at the surface. Sandy nutrient poor sites on sand sheet tundra have low annual phytomass production compared with nearby sites other loess derived types (Walker et al 2003).

Soils of *Eriophorum vaginatum* tussock tundra on broad slopes with show some profile development and have highly decomposed organic material. Tussock slope soils are somewhat poorly drained thaw ranges between 20 and 50 cm and the water table is never at the surface in late summer.

Conceptual Model



Climate Change:

The stability of sand sheet tundra is facilitated by permafrost, which generally rises as vegetation cover increases (Peterson and Billings 1978). Understanding the interaction between permafrost and plant communities of sand sheet tundra is the key to predicting their linked response to climate change. Changes to the active layer induced by climate change are likely to be affected by concurrent changes to the vegetation and soils. The details of the linkages between climate, vegetation, soils, and the active layer are not well understood (Benninghoff 1966, Klene et al. 2001, Shiklomanov and Nelson 2002, 2003, Vasiliev et al. 2003). In general vegetation shades the soils and provides insulation that reduces summer heat flux. Moss and organic matter in the soil increase the water holding capacity affecting the hydrological properties. Thick moss carpets and organic soil horizons decrease active layer thickness, consequently decreasing the depth to which water is able to drain because of the presence of permafrost (Kane 1997). This process of waterlogging, or *paludification*, is thought to be the driving mechanism behind long-term vegetation succession and changes in the active layer thickness in the low arctic (Walker and Walker 1996, Mann et al. 2002).

Fire:

The natural fire regime in the arctic is largely unknown. Historically tundra fires rare on the North Slope.

Assessment of vegetation succession along a century-scale chronosequence of tundra fire disturbances supports the hypothesis that tundra fires facilitate invasion of tundra by shrubs. Degradation of ice-rich permafrost was also evident at the fire sites and likely influenced changes in tundra vegetation following fire. Identification of previously unrecognized tundra fires that occurred in arctic Alaska may better understanding disturbance regimes and carbon cycling in the region (Jones et al. 2013).

Invasive Species:

Invasive plant species are rare in sand sheet moist tundra and are primarily associated with human development.

Development:

Infrastructure development will result in direct loss of habitat, and also have indirect effects on adjacent habitat. Mechanical disturbances result in compression of vegetation and soil, melting of buried ice, thermokarst subsidence, thermal erosion, mechanical erosion resulted in long lasting inhibiting influences on sand sheet vegetation at Fish Creek (Lawson 1978).

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Foothills Tussock Tundra

Background

Tussock tundra is the zonal vegetation of mesic landscapes of the Brooks Range foothills. The Tussock Tundra BpS occurs on foothill side slopes, valley bottoms, and low elevation rolling hills.

The Tussock Tundra BpS occurs on gently rolling foothill slopes underlain by weathered bedrock and residual soils, colluvium, glacial deposits, and deep loess deposits (Jorgenson and Grunblat 2013). Bedrock-controlled summits and ridges at the upper elevation limit of the foothills generally do not support tussock tundra vegetation; these regions are part of the Alpine Dwarf Shrub BpS. Side slopes and lower slopes of the Foothills Tussock Tundra BpS are underlain by ice-rich and organic-rich colluvium, closer to the Brooks Range, surficial deposits are of glacial origin. The lower foothills are underlain by deep loess deposits of Pleistocene origin (Martin et al. 2009). Sites are underlain by silty mineral soils with a shallow to moderately thick surface organic layer (Viereck et al. 1992). Acidic soils dominate on older landscapes (Walker et al. 1995). The permafrost is ice-rich, and the active layer is near the surface throughout the growing season. This region of the Brooks foothills is expected to be very sensitive to climate warming (Gooseff et al. 2009).

Distribution:

The Tussock Tundra BpS includes the following NSSI landcover classes: Tussock Tundra and Tussock Shrub Tundra. The Coastal Plain physiographic region is excluded from its distribution.

Vegetation:

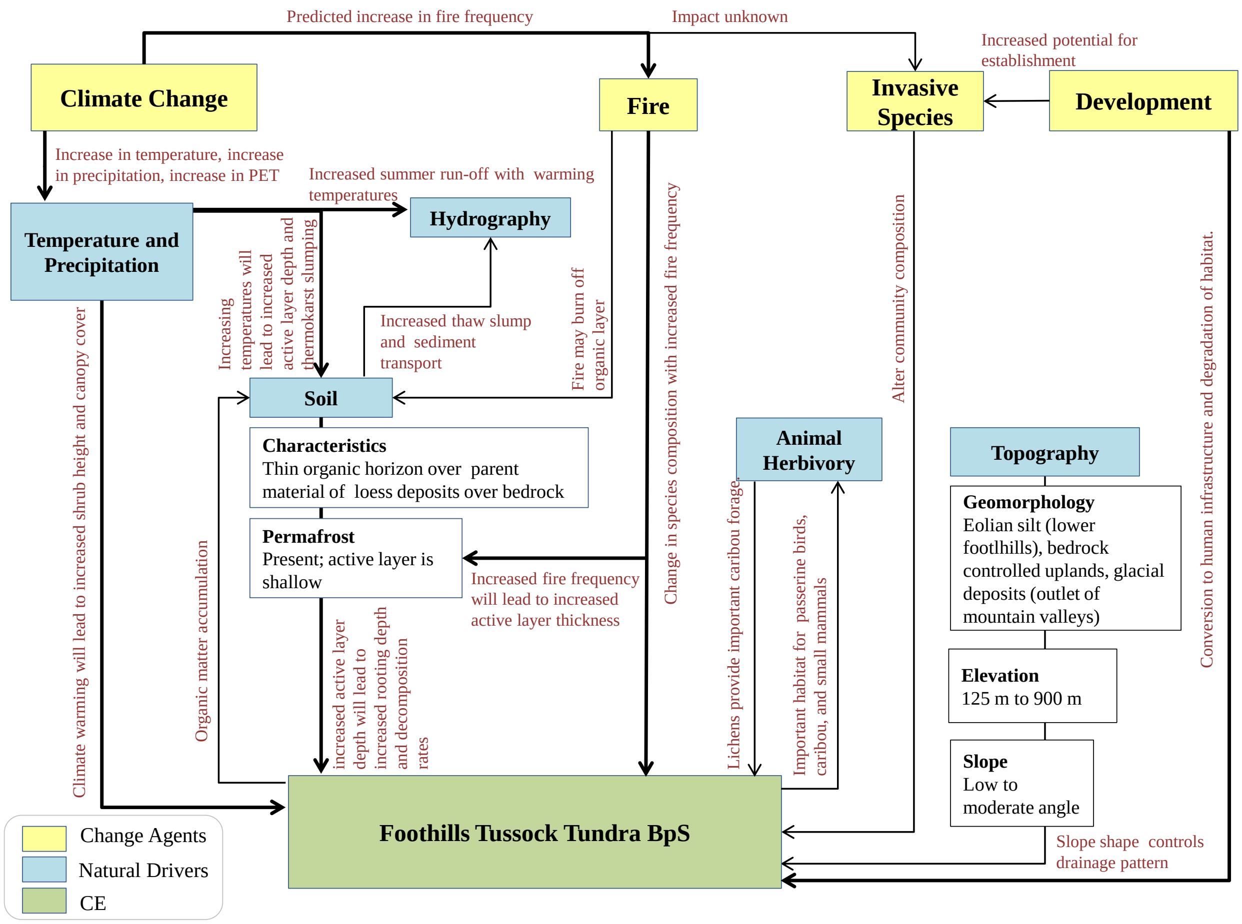
Tussock-forming sedges (*Eriophorum vaginatum* or *Carex lugens*) are typically the dominant species. Shrub cover is variable, but generally exceeds 25%. *Betula nana, Salix pulchra, Ledum palustre* ssp. *decumbens,* and *Vaccinium vitis-idaea* are the most common shrubs. Common nonvascular species include *Sphagnum* spp., *Hylocomium splendens, Cladina* spp., and *Aulocomnium* spp.

Eriophorum vaginatum requires silty mineral soil for establishment. Cryoturbation of surface deposits creates small-scale disturbance needed provide a substrate for seedling establishment. In the absence of soil disturbance, it is likely that the accumulation of acidic *Sphagnum*-derived peat deposits would lead to the eventual development of *Sphagnum*-ericaceous shrub heath vegetation (Walker et al. 1995).

Wildlife habitat:

The Tussock Tundra BpS provides important habitat for caribou (forage and calving grounds), small mammals (forage, shelter, and breeding), passerines and shorebirds.

Conceptual Model



Climate Change:

Increasing summer temperatures will cause an increase in the active layer depth and an increase in the depth of the rooting zone for vascular plants. A longer warm season will allow more subsurface soil moisture drainage and may lead to drying of the soils in late summer (Martin et al. 2009). An increase in the height and canopy cover of shrubs such as *Betula nana* and *Salix pulchra* has been observed in several locations across the North Slope and this trend is expected to continue (Sturm et al. 2001, Wahren et al. 2005, Tape et al. 2006). Cover of lichens may be reduced by increased shading and competition from shrubs and other vascular species.

Increasing temperatures may result in more frequent thaw slumps on ice-rich sloping terrain (Gooseff et al. 2009). Slumping may increase sediment transport into water track drainages and streams.

Fire:

Presently, tundra fires are infrequent north of the Brooks Range; however fire frequency is predicted to increase in tussock tundra habitats. Fire typically consumes the flammable leaves of graminoids, including *Eriophorum vaginatum*, but generally does not kill the meristematic tissue and roots. Lichens and bryophytes dry rapidly in low humidity and are an available fuel for tundra fires. Studies documenting post-fire succession in tundra are mostly from the Seward Peninsula (Racine et al. 2004) and may not be representative of the time scales that would be expected on the North Slope. Total vascular plant cover may return to pre-fire levels within 6 to 10 years following fire, primarily due to rapid basal resprouting of *Eriophorum vaginatum* tussocks. *Betula nana, Salix* spp., and ericaceous shrubs also resprout but their cover can remain well below pre-fire levels during the first 6 to 10 years after fire (Racine et al. 1987).

While vascular plant cover, production and biomass can recover to pre-fire levels within 10 years (Wein and Bliss, 1973, Racine et al 1987, Fischer et al. 1984), bryophyte and lichen communities are largely destroyed by fires in tussock tundra and their recovery rate is much slower. Following fire, bryophytes including *Marchantia polymorpha* and *Ceratodon purpureus* rapidly colonize in the inter-tussock spaces. These species appear to reach a maximum cover within five years after fire and then decline as the vascular overstory develops. The time required for successional return to pre-fire bryophyte species compositions and cover levels (e.g., *Sphagnum* spp., *Aulocomnium* spp., *Dicranum* spp., and *Hylocomium splendens*) is largely unknown, but likely to require a minimum of 25 years (Racine et al. 1987).

For the first 15 years following fire, crustose lichens and *Cladonia* squamules are reported to occur with high frequency, but at low (≤1%) cover (Jandt et al. 2008); 30-35 years post-fire, lichen cover in burned tundra was less than 5% (Holt et al. 2008, Jandt et al. 2008); 50–100 years after fire, *Cladina mitis*, *Cladina arbuscula* and other *Cladonia* spp. may reach peak abundance but are eventually replaced by late-successional species such as *Cladina stellaris* and *Cladina rangiferina* (Swanson 1996).

A severe fire will remove the surface organic material and increase soil warming resulting in an increase in the depth of the active layer (Yoshikawa et al. 2002). Fire will increase the potential for thaw slumps.

Invasive Species:

Invasive plant species may compete with native vegetation in the future. However, invasive species are currently limited in the North Slope study area and are not likely to expand enough within the next 50 years to have a major impact.

Development:

Infrastructure development will result in direct loss of habitat, and can also have indirect impacts on adjacent habitat. New development will increase the potential for aerial transport and deposition of fine sediment near roads, airstrips, and towns, and also increase the potential for sediment transport into waterways through erosion. Ice roads and winter trails can damage moist tundra vegetation, particularly tussock vegetation (Guyer and Keating 2005, Felix and Raynolds 1989). Compression of tussock and bryophytes can lead to changes in active layer depth and can result in a shift from moist tundra to wet sedge vegetation. These changes may lead to changes in drainage networks that may affect adjacent vegetation.

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Alpine Dwarf Shrub

Background

The Alpine Dwarf Shrub BpS is widespread throughout the Brooks Range and upper elevation foothills. It occurs on side slopes, low summits, and ridges. The substrate ranges from residual bedrock to colluvium, and sites are typically mesic and very well drained. On colluvial sideslopes in the mountains the Dwarf Shrub class is often interspersed with active scree slopes. Slopes range from gently sloping to steep and unstable. Permafrost is typically present, but the active layer may be deep, especially on south facing slopes.

Distribution:

Alpine Dwarf Shrub BpS includes the following NSSI map classes: Dwarf Shrub-Dryas, Dwarf Shrub-Other, and Dwarf Shrub Sedge. The Coastal Plain physiographic region is excluded from its distribution.

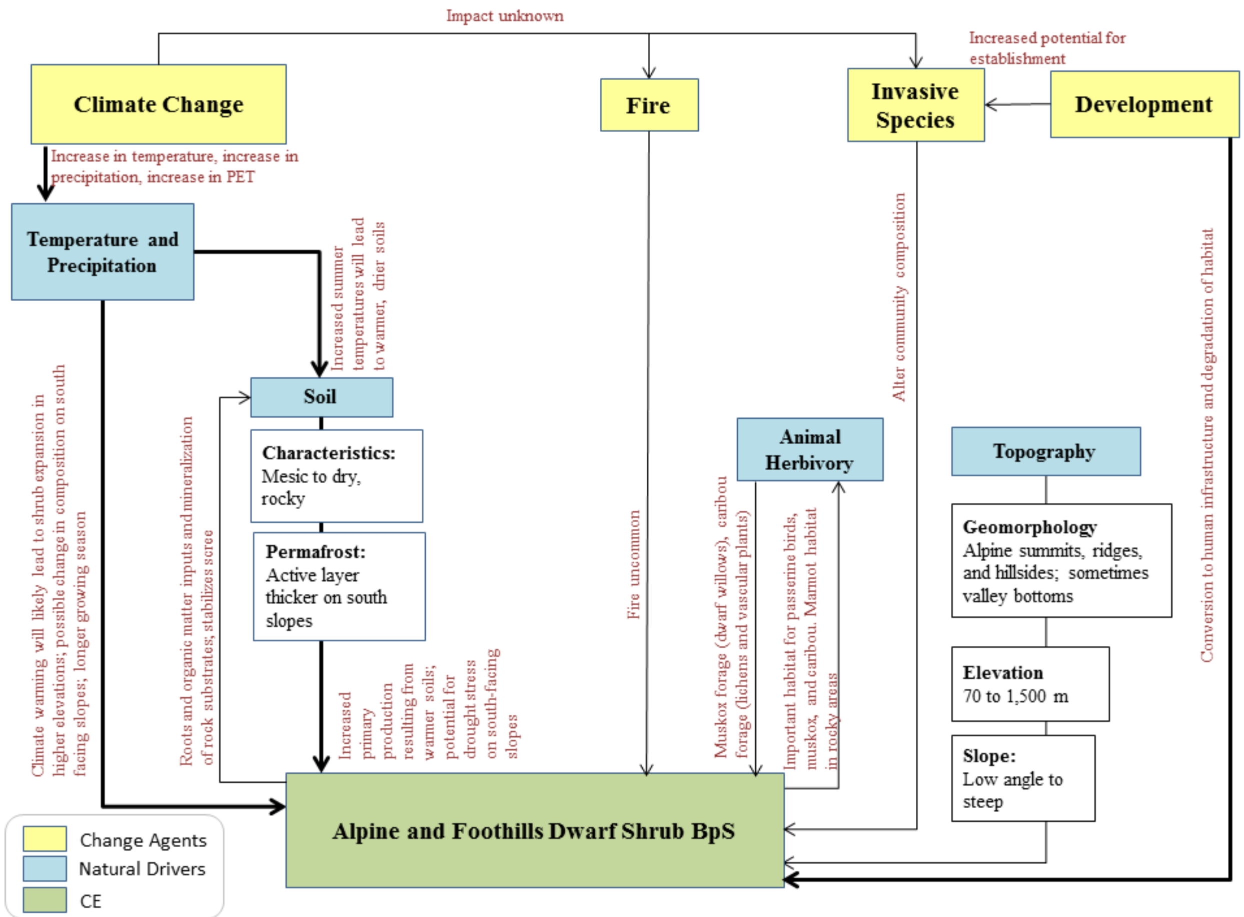
Vegetation:

Dominant shrubs are typically *Dryas octopetala, Cassiope tetragona,* and *Salix* spp. (including *Salix reticulata, S. arctica, S. phlebophylla, and S. puchra*). Other common shrubs include *Arctostaphylos alpina, Vaccinium uliginosum, V. vitis-idaea, Diapensia lapponica,* and *Loiseleuria procumbens. Carex lugens* can be common on low angle sites with adequate soil moisture. A wide variety of alpine forbs are present with low cover. Common non-vascular species include *Hylocomium splendens, Racomitrium lanuginosum, Dicranum* spp., *Polytrichum* spp., *Umbilicaria* spp., *Cladina* spp., *Peltigera* spp., and *Cetraria* spp.

Wildlife habitat:

The Alpine Dwarf Shrub BpS provides foraging habitat for muskox and caribou, breeding and foraging habitat for passerine birds, and breeding, foraging, and shelter for Alaska marmot.

Conceptual Model



Climate Change:

The rocky residual soils are thaw-stable and are not expected to exhibit significant geomorphic change under a warmer climate regime (Martin et al 2009). Changing moisture regimes may lead to changing shrub composition and phenology within the current Dwarf Shrub BpS, especially on south-facing slopes. Climate warming may lead to shrub encroachment upslope into alpine barrens.

Fire:

It is unknown whether the predicted increase in fire frequency will impact this BpS

Invasive Species:

Invasive plant species may compete with native vegetation in the future. However, invasive species are currently limited in the North Slope study area and are not likely to expand enough within the next 50 years to have a major impact.

Development:

Infrastructure development will result in direct loss of habitat, and also have indirect effects on adjacent habitat.

References

Martin, Philip D., Jennifer L. Jenkins, F. Jeffrey Adams, M. Torre Jorgenson, Angela C. Matz, David C. Payer, Patricia E. Reynolds, Amy C. Tidwell, and James R. Zelenak. 2009. Wildlife Response to Environmental Arctic Change: Predicting Future Habitats of Arctic Alaska. Report of the Wildlife Response to Environmental Arctic Change (WildREACH): Predicting Future Habitats of Arctic Alaska Workshop, 17-18 November 2008. Fairbanks, Alaska: U.S. Fish and Wildlife Service. 138 pages.

Floodplain Shrubland

Background

The Brooks Range, Brooks Range Foothills and Coastal Plain ecoregions contain many rivers that drain into the Arctic Ocean or Chukchi Sea, including the Kivalina, Utukok, Colville, Canning and Kongakut rivers. Many of the rivers or their tributaries originate in the Brooks Range as clear-water or occasionally silt-rich glacier-fed streams. These rivers typically have floodplains that support both dry to mesic terraces and also wetlands.

In this description we only include the dry to mesic floodplains and terraces. Floodplain wetlands are a separate Biophysical Setting. Ancient floodplain terraces no longer subjected to flooding are also not included in the following description.

Distribution:

Floodplains are widely distributed in the valleys of the Brooks Range and Brooks Range Foothills, and across the Coastal Plain ecoregions. The distribution is defined by the floodplain subsection and the following NSSI landcover classes: Dwarf Shrub-Dryas, Dwarf Shrub-Other, Low-Tall Willow, Alder, Sparsely Vegetated, and Barren.

Environmental Characteristics:

Floodplains are fluvial plains consisting of meandering or straight active streams, abandoned channels, and alluvial terraces. The formation of new land in floodplain ecosystems is well documented (Leopold et al. 1964, Friedkin 1972, Walker et al. 1982). Along a meandering river, alluvium typically is deposited on convex curves in the river channel. The opposing concave bank is cut, providing sediment for deposition on convex curves downstream and creating a series of similar bands of alluvial deposits. The channel thus meanders laterally across the floodplain. Vegetation growing on new deposits near the river may be contrasted with that on older deposits inland to recognize and measure successional processes (Walker 1985). Alluvium also is deposited on the soil surface during flooding further raising the soil surface height, but because surface height is a function of floodwater height, it eventually stabilizes (Leopold et al. 1964). Wind-blown sand and silt from the floodplain or adjacent dunes are also deposited on the floodplains and may form dunes or raise the level of the floodplain terrace surface.

The movement of a river across its plain determines the river channel pattern: straight, meandering or braided. Each pattern can be found on floodplains. Straight channels typically are formed because of high valley gradients, a constriction in the landscape such as a narrow valley bottom, or down-cutting through a terrace. Braided rivers have multiple, wide, shallow channels characterized by rapid erosion, deposition and channel shifts. Meandering rivers have one or two main channels that migrate like a whip or snake across its floodplain.

Vegetation associated with rivers is subjected to intense disturbance during spring breakup (Walker 1985). For example, when flow from upstream snow melt begins before the onset of melt downstream, ice dams may spread water over vast areas in arctic river deltas, reconnecting and recharging lakes (Martin et al. 2009).

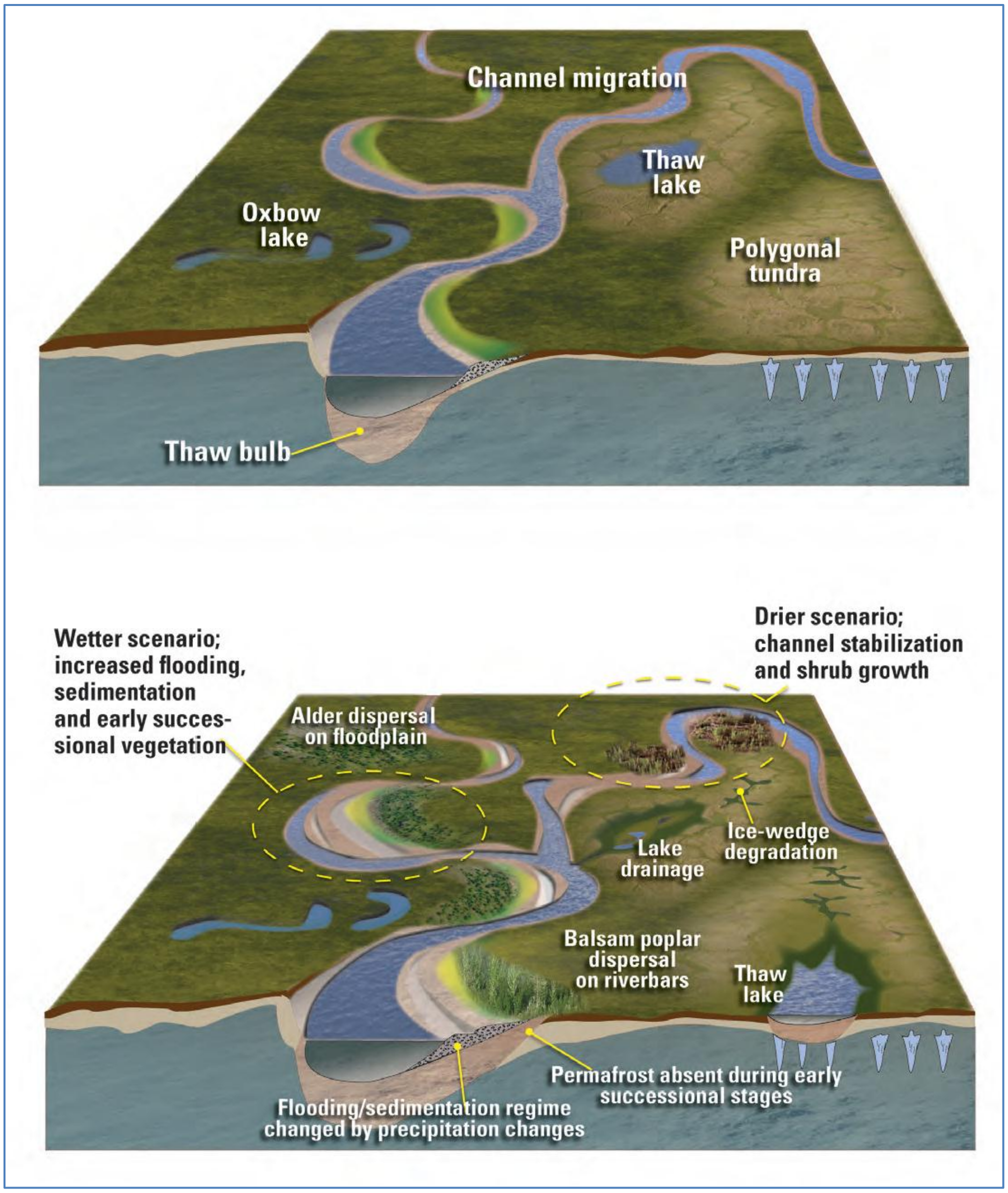


Figure 4. Schematic of arctic floodplain landscape, current (above) and projected (below). The projected landscape illustrates elements likely to change as a result of climate warming. Figure by R. Mitchell/Inkworks for WildREACH from cited sources.

Permafrost development is less conspicuous on active floodplains. This is partially due to better drainage in recently deposited alluvium than drainage on the adjacent landscapes, and the redeposition of alluvium by fluvial action tends to mask the more slowly acting permafrost processes. In time, segregated ice and wedge ice form on the older terraces which deforms the surface, affecting water runoff, and increasing the susceptibility of older terrain to thermokarst (Martin et al. 2009).

Aufeis, or river icings, is another distinct feature on floodplains. These ice bodies form during winter in river sections where there is constriction between the river bed and overlying ice (Walker et al. 1982). The resulting hydrostatic pressure cracks the ice and allows water to flow over the surface, where it freezes in a thin layer. Numerous layers will freeze forming the thick ice deposits, which do not melt the following summer. These features often occur downstream from perennial springs, which supply a constant source of water during the winter (Childers et al. 1977).

Vegetation:

Early seral: Early seral floodplain deposits or recently disturbed sites on floodplains are typically dominated by the *Salix alaxensis* Sparse (Floodplain) Plant Association. Other common associations include *Equisetum variegatum, Chamerion latifolium–Artemisia alaskana* Sparse (Floodplain), and a sparse cover of *Salix glauca*. Other common early seral species include the shrubs *Arctostaphylos rubra, Dryas integrifolia*, and herbaceous species *Festuca rubra* ssp. *arctica, Artemisia alaskana, Artemisia tilesii, Hedysarum boreale* ssp. *mackenziei* and *Oxytropis campestris*. The cover of bryophytes, such as *Bryum* spp., sometime exceeds 25%.

These sites are dry during low flows to wet when flooded. The soils are typically sand, gravel or cobble C horizons, the pH ranges from 6.9 to 8.5, and we did not encounter permafrost to 1 m deep.

Mid seral: More stable sites on active floodplains and small active streams typically support various low and tall willow associations. The most common is the *Salix alaxensis* association, and other associations include *Salix alaxensis / Dryas octopetala, Salix arbusculoides, Salix glauca, Salix niphoclada, Salix pulchra, Salix richardsonii*, and the *Alnus viridis* ssp. *fruticosa / Arctagrostis latifolia* (provisional) associations. The understory species composition is highly variable. Some shrubs may have high cover including *Salix phlebophyll*a, and *Salix reticulata*. Herbaceous cover is often sparse, but in more mesic sites, such as river oxbows, herbaceous cover may be high including *Anemone parviflora, Equisetum arvense, Eurybia sibirica, Hedysarum boreale* ssp. *mackenziei, Calamagrostis canadensis* and *Poa arctica*. Bareground, rock and litter often have high cover. Moss cover ranges from sparse to high and lichen cover is typically sparse.

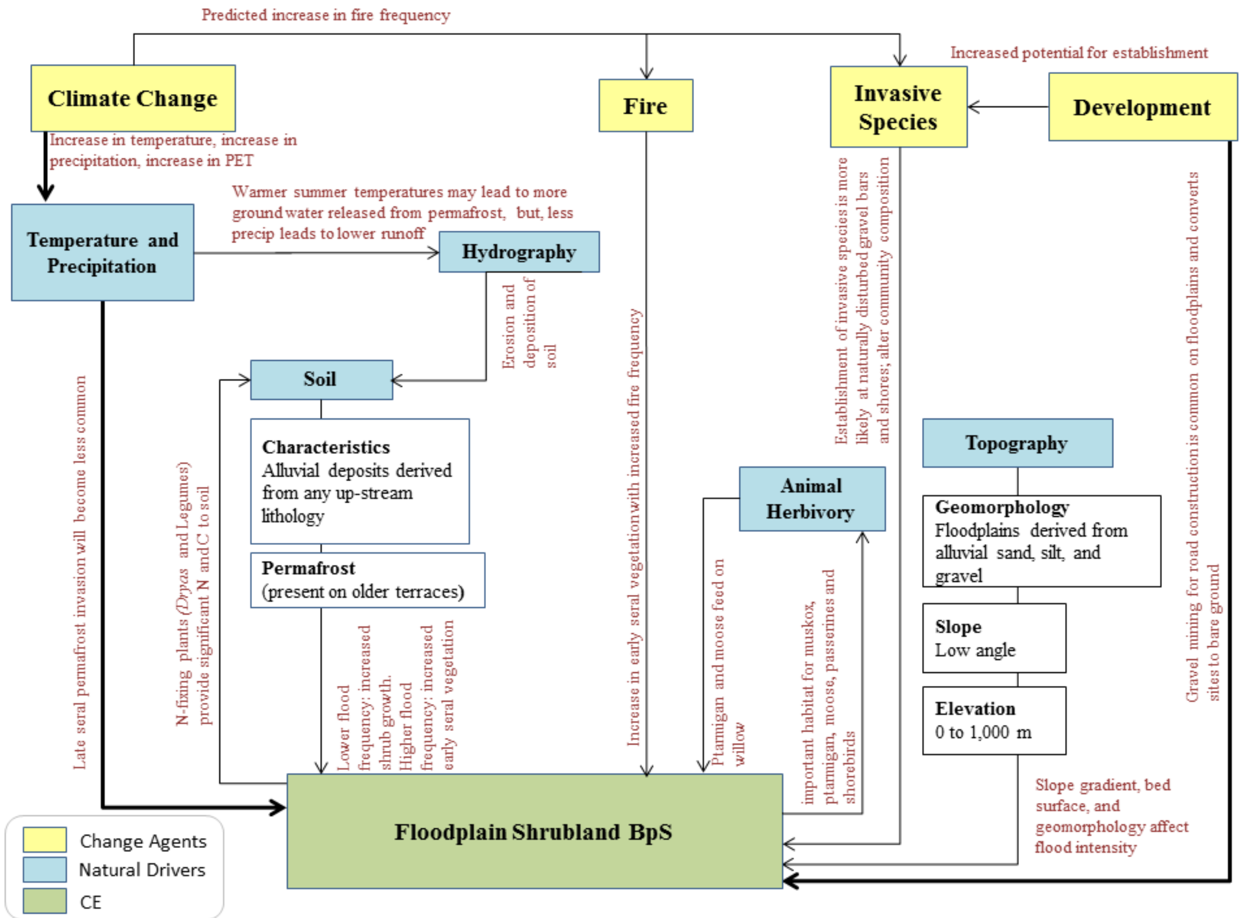
The sites are relatively dry except during flooding, and mesic on some overflow channels. The soil surface is either bare alluvium or a thin organic mat over silt, sand and rocks, and layered fines caused by vertical accretion of silts during overbank flooding, or layered organics and silts created by the accumulation of organic matter between infrequent flooding events (Shur and Jorgenson 1998). We did not encounter permafrost at 40 cm deep, and the water table typically > 40 cm. The pH ranges from 6.7 to 7.7.

Late seral: On dry to mesic floodplain terraces with infrequent flooding, the most common association is *Dryas integrifolia* (Floodplain) (Jorgenson et al. 1994, Walker 1985, Walker et al. 1997). Species composition is highly variable. *Dryas integrifolia* dominates or co-dominates with other shrubs such as *Andromeda polifolia, Arctostaphylos rubra, Betula nana, Salix phlebophylla, Salix reticulata* or *Vaccinium uliginosum*. It may also co-dominate with herbaceous species such as *Carex lugens, Carex membranacea, Carex obtusata, Carex scirpoidea* and *Equisetum arvense*. Total moss cover ranges up to 65% and may include *Aulacomnium turgidem, Drepanocladus* spp., *Hylocomium splendens* and *Sanionia uncinata*.

These are dry to mesic inactive floodplain terraces. The soils are a thin organic horizon over a sandy C or B horizon. Permafrost occurs, but typically deeper than 40 cm and the water table is deeper than 40 cm.

The pH ranges from 6.4 to 7.1.

Conceptual Model



Climate Change:

The following is a hypothesis presented by Marin et al. (2009) on physical and biological changes on floodplains due to climate change. “Riverine ecosystems could respond to climate change in a variety of ways depending on the amount of warming and the balance between evapotranspiration and precipitation. In response to warming, permafrost aggradation will be retarded in the barren portions of active floodplains, and degradation will be accelerated on the inactive and abandoned floodplains. Ice wedges formed in the later stages of floodplain development will degrade, thus lowering the water table and instigating formation of drainage networks that will accelerate drainage of riverine lakes. The consequences of altered precipitation (amount, seasonality, and frequency of extreme events), discharge, flooding, sedimentation, and erosion are more uncertain. Many of these processes are more sensitive to extreme events rather than to average conditions. A scenario of increased precipitation will be accompanied by increased flooding, sedimentation, and erosion. This, in turn, should favor more productive early successional ecosystems. In contrast, decreased runoff associated with drying during midsummer may lead to increased channel stability and increased shrub growth on the stabilized active floodplain.”

“Patches of balsam poplar forest occur in scattered locations across the northern Brooks Range and Foothills, in floodplain settings with year-round groundwater flow (Bockheim et al. 2003). They also occur in numerous small patches on floodplains and hillsides in northwestern Alaska where mean annual air temperatures are -6 to -8 °C (Jorgenson et al. 2004). Because these trees release highly mobile wind-dispersed seeds and are adapted to growing on well drained, early successional habitats, balsam poplar should be able to rapidly advance down floodplains across arctic Alaska in response to warming temperatures.”

Fire:

Fires rarely occur in this BpS. An increase in fire frequency would lead to an increase in early seral shrub communities.

Invasive Species:

Invasive plant species are rare in this BpS and are primarily associated with human development. Establishment of invasive species is more likely at naturally disturbed gravel bars and shores and will alter community composition.

Development:

Historically, much of the gravel used for construction of roads and pads in arctic Alaska has been obtained from deposits within the floodplains of large rivers. Gravel mining in floodplains of large rivers has been shown to substantially alter flow regimes of large river systems (Joyce 1980).

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Appendix B: Conceptual Models for Aquatic Coarse-Filter CEs

Conceptual Models and model descriptions for deep and shallow connected lakes and large and small streams.

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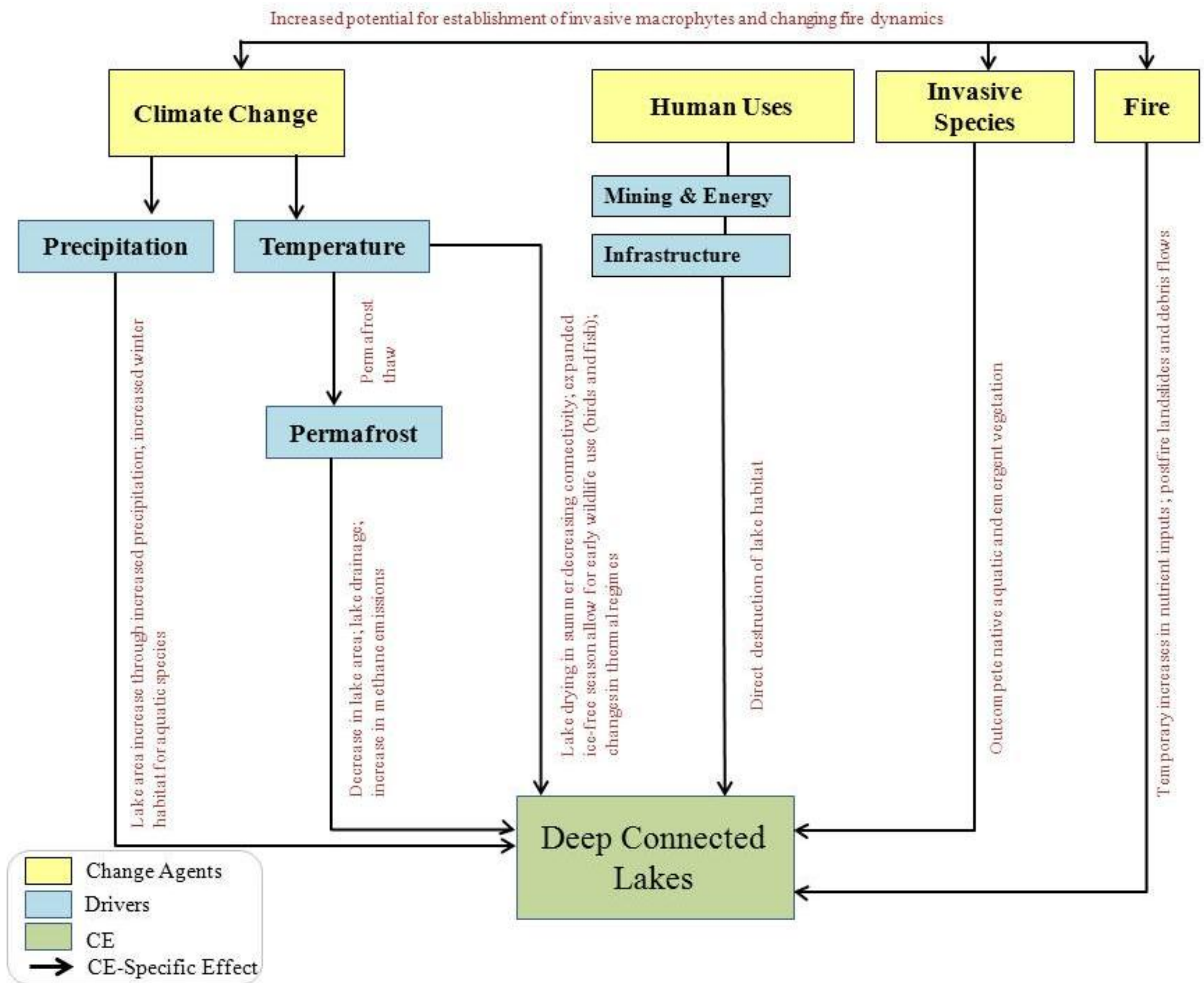
Deep and shallow connected lakes

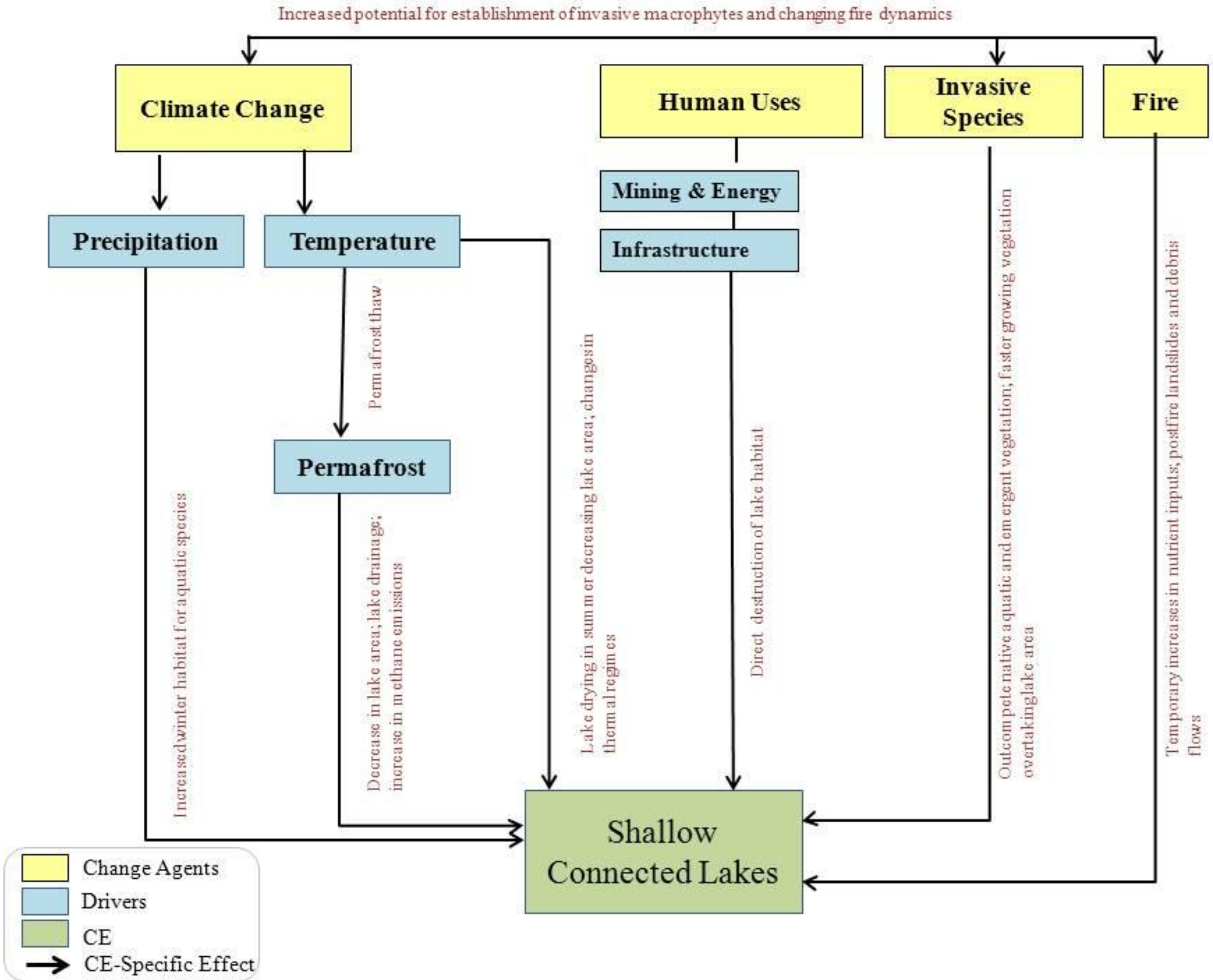
Background

Deep and shallow connected lakes throughout the North Slope study area support a rich biodiversity of aquatic organisms and represent important foraging and breeding habitat for aquatic insects, fish, waterfowl and shorebirds. Additionally, lake ecosystems provide important recreational and personal uses for local residents (e.g., subsistence harvest of fish and wildlife).

Deep connected lakes are generally 2–4 m in depth (Mellor 1982) and characterized by low temperatures, low prey densities, short open water periods, and limited overwintering habitat. Because of their depth and perennial flow, it is less likely that deep connected lakes freeze completely during winter, therefore providing important winter refuge for fish and other aquatic organisms. Shallow lakes (generally less than 2 m depth) are ubiquitous on the North Slope and represent approximately 40% of the landscape (Sellmann et al. 1975, Hinkel et al. 2005). Shallow lakes typically freeze to the bottom and only contain liquid water during the summer months (Kolzenko and Jeffries 2000). Shallow lakes do not provide fish overwintering habitat but may be used by fish during the open water season. Most shallow lakes are dependent on surface runoff for recharge and are subject to substantial evaporative loss during summer (Miller et al. 1980). Lake connections can vary greatly and change throughout the open-water season, with ephemeral connections commonly occurring during high flows in the spring.

Conceptual Model





Climate Change

Lake ice melt plays an important role in the break-up of spring ice on the North Slope. Increased air temperature will delay freeze-up and shorten the period before break-up thereby lengthening the ice-free season. Warmer temperatures combined with increased snow cover are expected to have a significant impact on the annual heat budget of arctic lakes (Schindler and Smol 2006). Increased snow cover will insulate lakes and result in thinner ice. Reduced ice cover will create new habitat, especially in lakes that are currently frozen for most of the year. Thinner lake ice will melt faster in spring, leading to earlier break-up of spring ice and earlier seasonal rise in water temperature. Earlier ice break up could result in channel blockage for lakes with connected streams.

Fish access, as well as nutrient status, is related to the degree of connectivity within lake systems. Warmer temperatures coupled with increased evapotranspiration, especially later in the summer and early fall, could cause a drying effect which would lead to a lack of connectivity between streams and lakes. A lack of connectivity between inlet and outlet streams would limit access to important spawning areas, affect the amount of available overwintering habitat, and potentially disrupt the timing of annual migrations for fish species. Changes in the freeze-thaw cycle that affect lake connectivity could alter migration movements of fish species such as broad whitefish that move into deeper connected lakes in the winter and migrate to shallower lakes for feeding and spawning in the summer.

Snow melt during the spring is the primary source of water and nutrient recharge to both deep and shallow connected lakes on the North Slope. Drier and warmer summer temperatures could affect the amount of snow melt available in the spring because a greater proportion of snow melt may be taken up to recharge lakes and absorbed into soils. Similarly, with increased temperatures, additional snow melt in lakes within areas that have thicker permafrost could result in increased lake area. These changes would be temporary if temperatures continue to rise.

Loss of permafrost increases the potential for many shallow connected lakes on the North Slope to decline in area or dry out completely. For example, thawing permafrost and increased evaporation (related to warmer weather) has been linked to increases in substrate permeability and drainage for deep and shallow lakes in Alaska (Roach et al. 2013). However, other studies have documented an increase in lake area as a consequence of melting and erosion surrounding ice wedges (increased snow melt and permafrost thaw). Thus, lakes may drain entirely with permafrost melting, or lake levels may rise with increased inflow (at least temporarily). Lastly, melting permafrost could temporarily increase nutrient loading to lakes which would increase primary productivity (Hobbie et al. 1995) and benefit numerous wildlife species that forage in these lakes. In addition to direct effects on lake habitats, thawing permafrost along lake margins could increase the amount of methane released from lakes to the atmosphere (Walter et al. 2007).

Fire

Fire removes stabilizing vegetation from the landscape and can result in an increase in erosion and runoff, resulting in higher sediment inputs to aquatic systems. Increased runoff has the potential to decrease both primary productivity and aquatic invertebrate populations through increased turbidity. The increases in erosion and runoff in burned areas also increase nutrient inputs to aquatic habitats (Davis et al. 2013). These effects are temporary and are limited by the re-establishment of vegetation.

Anthropogenic Uses

Construction or development, especially oil and gas operations near deep connected lakes could increase sedimentation to lakes. Oil and gas activities near streams that are connected to lake systems could also have negative impacts on the water quality of connected lakes. Run-off from unpaved roads can result in sedimentation to lakes increasing the turbidity of lake waters and impacting the quality of water for aquatic organisms and human use. Changes in water quantity caused by withdrawals during exploration are typically from deep lakes during winter, while water withdrawals during operations and for domestic uses would also occur during the open-water season. Winter withdrawal from lakes for the creation of roads and other infrastructure has the potential to negatively impact overwintering fish populations, disrupting connectivity to other waterbodies, or reducing lake area. Increased development, especially the construction of new roads can also as facilitate the dispersal of invasive species into lakes. Furthermore, with increased road access communities may increase fishing pressure and possibly impact water quality of lake habitats within the North Slope study area.

Invasive species

Invasive plant species have the potential to outcompete native aquatic and emergent vegetation. However, few invasive plant species have been documented within the North Slope study area and no invasive aquatic species have yet been documented. *Elodea* spp is an invasive aquatic plant that has recently been documented in south central Alaska and Chena slough, near Fairbanks. *Elodea* spp generally invade and outcompete other aquatic plant species in slow moving streams or small, shallow lakes and ponds. Thus, shallow connected lakes may be more susceptible to potential *Elodea* spp invasions than deep connected lakes.

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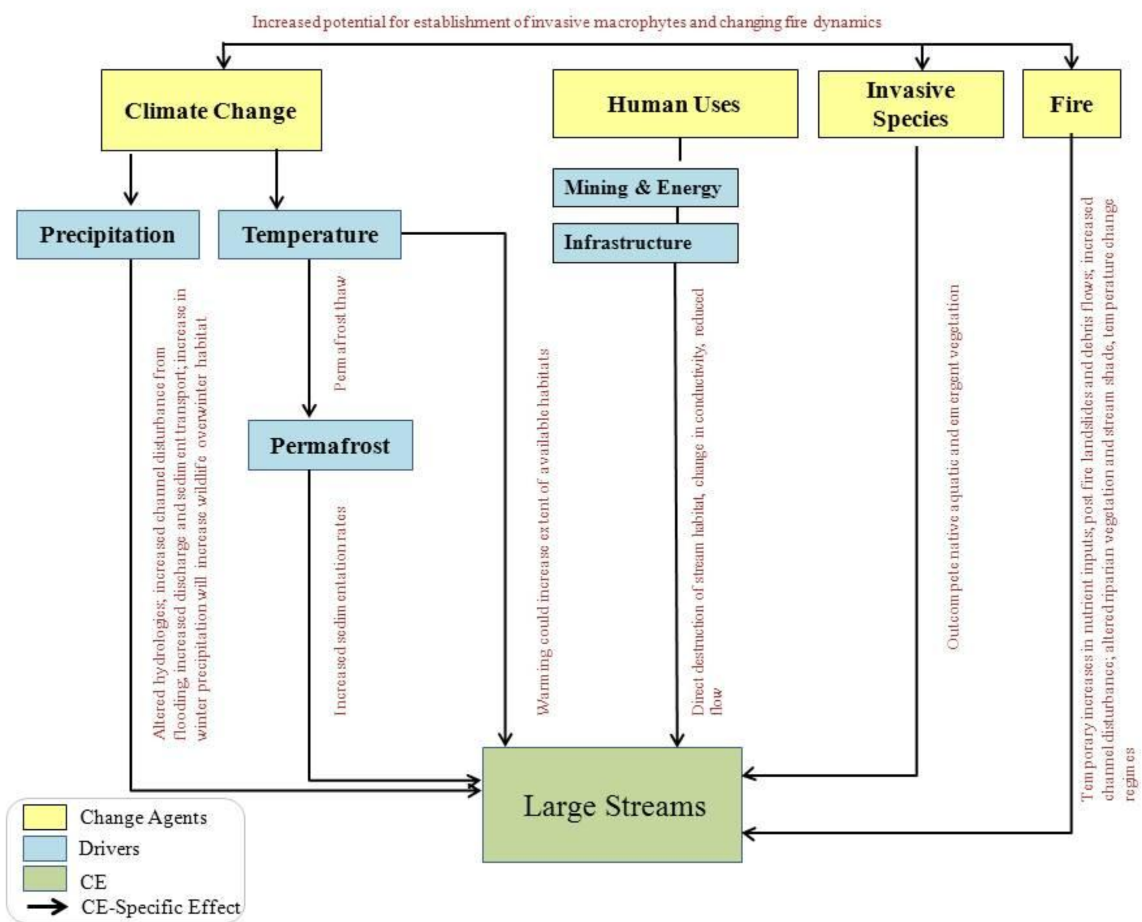
Large and Small Streams

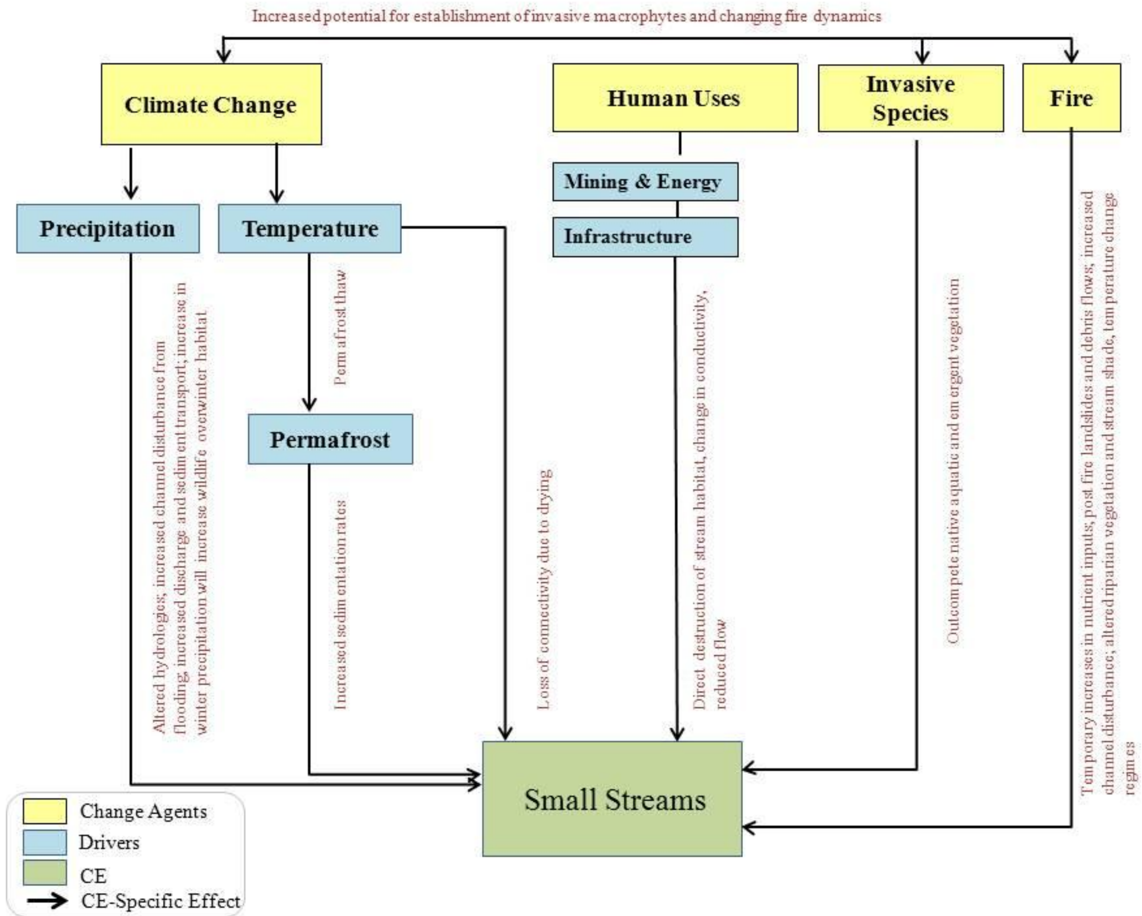
Background

Within the North Slope study area, large and small stream ecosystems provide important habitat for aquatic insects, fish, and waterbirds. Large streams are those with sufficient flow to allow for springs and deep pool areas, and overwintering habitat. Small streams are generally slow moving and freeze completely during the winter. However, some small streams may provide overwinter habitat in the form of springs and deep pools.

Stream ecosystems support extensive spawning and rearing habitat for numerous fish species on the North Slope. Streams also provide important habitat for aquatic invertebrates. Additionally, large and small streams on the North Slope provide important transportation and recreational uses for local residents. Large streams are typically less productive than smaller streams due to warmer temperatures in smaller tributaries (Hobbie 1984). Consequently, smaller streams are often preferred summer feeding habitat for many fish species and aquatic insects.

Conceptual Model





Climate Change

Stream ecosystems within the North Slope study area could respond to increased precipitation, warmer air temperatures, decreased snowpack, permafrost thaw, and increased wildfire activity in a variety of ways. Future precipitation scenarios for the North Slope study area are somewhat unclear, but there is a general projected trend for increased winter precipitation. An increase in precipitation will be accompanied by increased flooding, sedimentation, and erosion which could have negative impacts for stream ecosystems of this region. However, increased winter precipitation may increase stream overwinter habitat areas for fish and wildlife species. If warmer, drier weather is expected in summer, than there would be a decrease in runoff which could result in channel stability. With summer temperature increases, warmer water temperatures could modify the distribution of aquatic organisms by, 1) limiting movements through stream networks because of thermal barriers, or 2) increasing available habitat in streams where cold temperatures previously limited habitat suitability (e.g., upstream areas). Furthermore, warmer summer temperatures could result in low flow periods in streams that could have serious implications for the biotic potential of a stream (e.g., lower dissolved oxygen, higher density of spawning fish resulting in mortality).

Permafrost thaw during winter has been shown to enhance groundwater discharge to streamflow within other parts of Alaska (Brabets and Walvoord 2009). Changes in groundwater flow, especially during spring/winter could alter the timing and extent of ice cover and alter stream habitats by directly impacting aquatic organisms (e.g., fish migrations) and by changing stream velocities, water temperatures, concentrations of suspended sediments, and cause scouring (Prowse 2001). Small streams are especially dependent on perennial stream flow. Permafrost thaw and an increase in depth of the active layer could alter stream hydrology, increase channel disturbance from flooding, and increase discharge and sediment transport (Dingham 1973). Fish spawning areas might be especially susceptible to the effects of permafrost thaw as scouring of eggs and destruction of spawning habitat are likely. However, studies within the North Slope have found a link between permafrost thaw and increases in nutrients such as nitrogen and phosphorous which could have positive impacts for aquatic organisms that rely on stream habitats (Bowden et al. 2008).

Ice breakup is a major driver of important events that supply riparian habitats with the essential influx of sediment, nutrients, and water. Ice break up is critical to morphological changes such as channel enlargement, scour of substrate habitat, and the removal and/or succession of riparian vegetation. Additionaly, the timing of fish movements and migrations depend on the timing of freeze and thaw events and changes in these annual cycles could affect the phenology and movement of many aquatic species.

Fire

Changes in wildfire extent and severity could have important compounding effects on stream ecosystems. Increased wildfire activity could result in warmer stream temperatures, altered stream hydrology, increased landslides, and altered channel disturbances. Additionally, fires that burn across small streams may cause fish mortalities from excessive temperatures, although these effects are often short term (Hitt 2003). Fire can also alter riparian vegetation and stream shade (Pettitt and Naiman 2007), resulting in more chronic thermal effects within streams.

Anthropogenic Uses

Construction or development along stream margins will alter stream channels and lake connectivity, remove or impair riparian vegetation and function, and increase sedimentation to important aquatic habitats. Similarly, removal of vegetation along streams banks for construction or infrastructure development can alter stream thermal regimes (Moore et al. 2005). These activities could have cascading negative effects on stream resources and aquatic organisms within the North Slope study area.

Invasive species

Invasive plant species have the potential to outcompete native aquatic and emergent vegetation. However, few invasive plant species have been documented within the North Slope study area and no aquatic species have yet been documented. *Elodea* spp is an invasive aquatic plant that has recently been documented in south central Alaska and Chena slough, near Fairbanks. *Elodea* spp generally invade and outcompete other aquatic plant species in slow moving streams or small, shallow lakes and ponds. Thus, small streams with slow moving waters would be most susceptible to invasion of *Elodea* spp, but many other variables such as proximity to roads and transportation hubs are important indicators to the likelihood of *Elodea* spp colonizing stream habitats within the North Slope study area.

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Appendix C: Conceptual Models for Terrestrial Fine-Filter CEs

Conceptual Models, model descriptions, and attributes and indicators tables for the following terrestrial species or species assemblages:

caribou
Greater white-fronted goose
raptor concentration areas
nearctic brown lemming
Lapland longspur
arctic fox
Willow ptarmigan

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Caribou (*Rangifer tarandus*)

Background

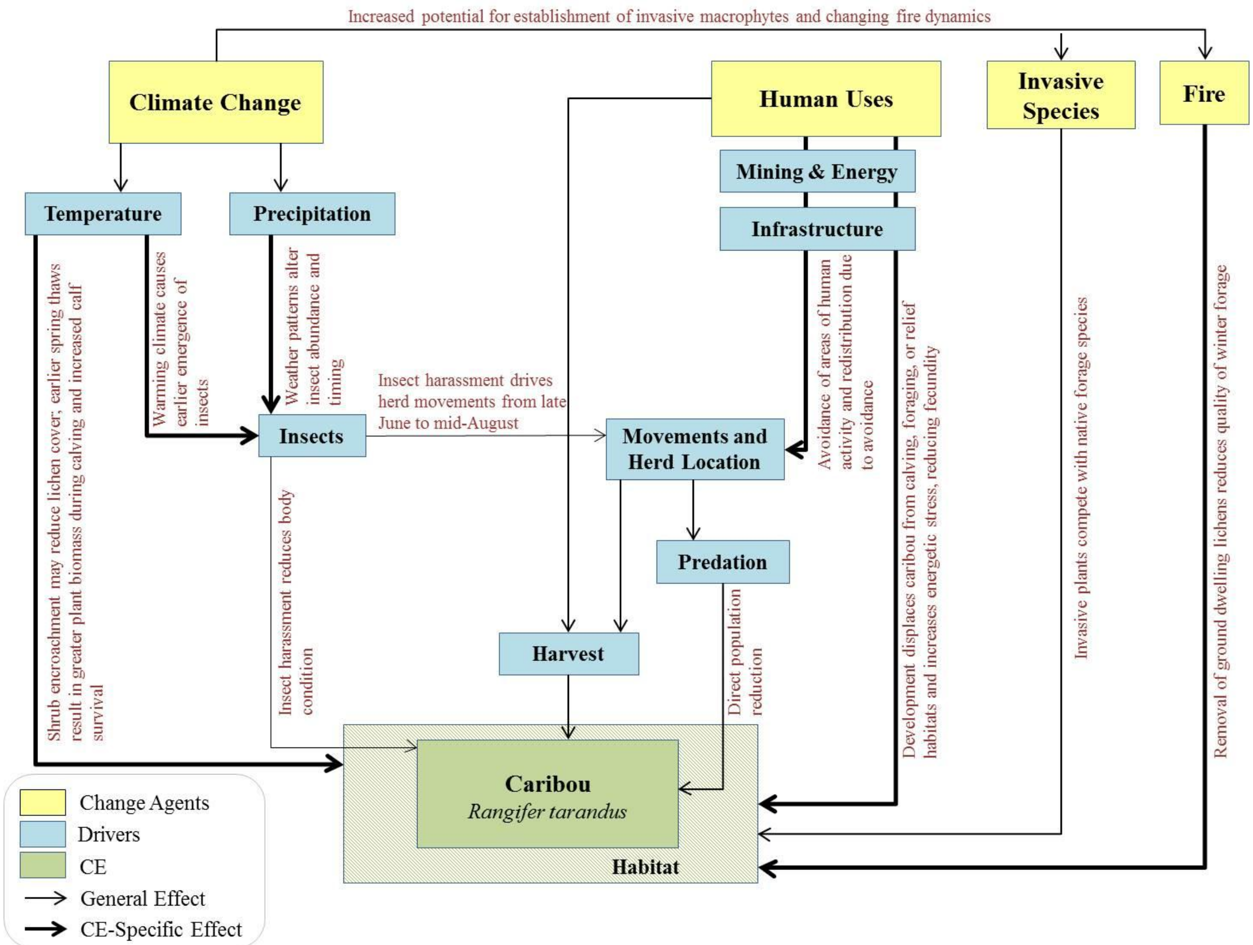
Caribou are circumpolar in their distribution, occurring in arctic tundra and boreal forest regions in North America and Eurasia (MacDonald and Cook 2009). In Alaska there are 31 recognized herds of which four are found within the North Slope REA boundary. The Western Arctic Caribou Herd occupies the western portion of the study area, the Teshekpuk Lake Caribou Herd occupies the western central portion of the study area, the Central Arctic Caribou Herd occupies the eastern central portion of the study area and the Porcupine Caribou Herd occupies the eastern portion of the study area and ranges into Yukon and Northwest Territories. These herds support a wealth of predator biodiversity and are an important source of food sustaining the health and culture of northern communities (McLennan et al. 2012).

Caribou of all four herds exhibit similar phenology. During spring (April and May), caribou migrate toward calving grounds on the Beaufort Coastal Plain. Calving peaks around the first week in June (MacDonald and Cook 2009). During summer, forage includes willow leaves, sedges, flowering plants, and mushrooms (ADF&G 2013). In general, forage production is greater at inland sites versus coastal sites. In addition, well-drained areas with greater variation in microscale relief are better foraging sites than flat, wet areas (Murphy and Lawhead 2000). Caribou rely on summer forage to obtain enough energy for reproduction (fetal development and lactation; Parker et al. 1990), body and antler growth, pelage replacement, and rebuilding nutrient stores for the upcoming winter (Joly and Klein 2011).

From late June to mid-August, caribou often form large aggregations, with insect harassment (mosquitoes, blackflies and oestrid flies) being the primary driver of caribou movements (Downes et al. 1985). Caribou of the Porcupine and Western Arctic herds move to windswept ridges and snow fields to avoid mosquitos while caribou of the Teshekpuk Lake and Central Arctic herds stay on the coastal plain seeking local insect relief areas on the coast where temperatures are lower and wind speed is higher. At the end of July, mosquito harassment abates and caribou of the Teshekpuk Lake and Central Arctic herds move inland where forage quality is higher (Murphy and Lawhead 2000).

As winter approaches, caribou generally migrate south to winter ranges on the Seward Peninsula, Brooks Range, Brooks Foothills, Richardson Mountains, and Ogilvie Mountains, although some caribou of the Teshekpuk Lake Herd remain on the coastal plain in the winter. Winter forage primarily consists of ground dwelling lichens (Murphy and Lawhead 2000).

Conceptual Model



Climate Change

Warming temperatures will alter the overall phenology of the region, including earlier snowmelt and plant growth (Sparks and Menzel 2002, Stone et al. 2002). These changes will alter the abundance and timing of both caribou forage and insect abundance/emergence. Predicted changes in temperature and vegetation phenology are expected to lead to changes in the summer habitats used by caribou as the four herds roam the artic coastal plain in summer, seeking out high quality plants to replenish energy and protein lost during winter. The phenology, nutrient content and abundance of plant forage throughout the short summer growing season are critical for caribou survival and reproduction.

Warming temperatures will increase the likelihood of advanced spring thaw, expediting vegetation emergence and increasing forage abundance at the time of calving. Earlier plant emergence may result in earlier parturition (Post et al. 2003) and increased calf survival (Griffith et al. 2002). Alternatively, early onset of the growing season, where caribou arrive on the calving grounds after the vegetation has passed through its optimal state of nutrition, could have adverse effects on calf survival (McLennan et al. 2012). In addition, earlier spring thaw and warmer spring temperatures may result in earlier insect emergence, which may cause a longer season of mosquito harassment and advance the need for insect-avoidance strategies (Fancy 1983, Murphy and Lawhead 2000, Witter et al. 2012).

Earlier plant emergence and increased plant growth (due to warming temperatures) may be beneficial for summer foraging, however, an increase in graminoid and shrub biomass can be detrimental to the growth of nearby shade-intolerant lichen (winter forage) (Walker et al. 2006).

Rain-on-snow (icing) events are currently infrequent in the North Slope study region, however, frequency is expected to increase with climate change (Hansen et al. 2011). These events alter the snowpack and can restrict foraging or increase energy expenditure causing negative impacts on reproduction and recruitment (Hansen et al. 2011, Joly et al. 2010).

Warmer annual temperatures may create territorial overlap of caribou and other ungulates moving into the region. This overlap may increase exposure to parasites and disease. However, given the extreme northern extent of the North Slope study region, range extension by more southern ungulate species into the area are not likely within the next 50 years.

It remains unclear whether the above mentioned changes will cumulatively result in a positive or negative impact for tundra dwelling caribou. The negative factors need to be balanced against the potentially positive effects of increased biomass of caribou forage, and overall warmer winter temperatures (Griffith et al. 2002, McLennan et al. 2012).

Fire

Potential increases in burned area through predicted climate-driven increases in fires can destroy ground dwelling lichens, removing the primary winter forage for caribou (Joly et al. 2003, Rupp et al. 2006). Lichens are a critical component of winter diet for caribou. Reduced lichen abundance, and thus a deterioration of winter range, can lead to shifts in winter distribution (Joly et al. 2010). The quality of winter forage can affect body condition, fetal development, birth weights and growth rates of calves, and milk production (White 1983, Parker et al. 2005). Lichens can take several decades to regenerate to pre-burn cover (Jandt et al. 2008).

Invasive Species

Invasive plant species may compete with native forage species in the future. However, invasive species are currently limited in the North Slope study area and are not likely to expand enough within the next 50 years to have major impacts on caribou habitat.

Anthropogenic Uses

Resource extraction and infrastructure development have caused the fragmentation of caribou habitat throughout Alaska. Patch sizes are likely to decrease with increased development. While a previous study in Prudhoe Bay found that caribou cows and calves did not avoid drilling areas (Fancy 1983), more recent studies have found that caribou generally avoid areas of human activity (up to 50–95% reduced presence, Vistnes and Nellemann 2008) and can be displaced from preferred calving grounds by human disturbance (Joly and Klein 2011 Wolfe et al. 2000). In addition, human activities can result in increased vigilance and avoidance behaviors which increase energy expenditure of individuals (Fancy 1983 Wolfe et al. 2000). Human activity may also cause a redistribution of animals on the landscape (Wolfe et al. 2000).

The Central Arctic Caribou herd has coexisted with oil field development around Prudhoe Bay for more than three decades. Construction of oil field infrastructure can displace caribou from the area. In the Milne Point Road area, caribou density decreased as road density increased, despite the overall concurrent population growth of the Central Arctic Caribou Herd (Noel et al. 2004, Joly et al. 2006). While some caribou have occasionally used gravel pads and roads as insect relief areas (Fancy 1983), infrastructure can typically delay or redirect caribou moving towards coastal areas to seek mosquito relief. If displacement from breeding, foraging, and relief habitats cause energetic stress, then affected cows will likely respond with lower fecundity (Murphy and Lawhead 2000, Vistnes and Nellemann 2008). Birth rates for female caribou in the Central Arctic herd exposed to areas of oil development were 10 to 20% lower than those not exposed to oil development (Cameron et al. 2005). The Western Arctic Caribou Herd currently has little contact with industrial infrastructure, except around the Red Dog Mine. The Teshekpuk Lake and Porcupine herds do not have significant contact with industrial infrastructure in Alaska, although the Porcupine herd does encounter road corridors in the Yukon Territory (Murphy and Lawhead 2000).

Increased road development and human access to caribou ranges may increase hunting pressure on the herds.

Harvest and Predation

Caribou are important in the region to subsistence hunters in the North Slope Borough as well as sport hunters. Human harvest tends to remove larger healthier animals of both genders. All herds receive some hunting pressure, with the majority of animals taken from the Western Arctic Caribou Herd.

Gray wolves (*Canis lupus*), grizzly (brown) bears (*Ursus arctos*), and Golden eagles (*Aquila chrysaetos*) feed on caribou, although grizzly bears and Golden eagles primarily feed on calves. Predator densities are lower on the Beaufort Coastal Plain than the Brooks Foothills or Brooks Range (Murphy and Lawhead 2000).

Attributes and Indicators

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating: Poor	Indicator Rating: Fair	Indicator Rating: Good	Indicator Rating: Very Good	Basis for Indicator Rating	Comments
Climate	Length of growing season	Number of days between date of spring thaw (DOT) and date of spring freeze (DOF)	Reproductive success; Forage quality and availability	Less than average		Average	More than average	Sparks and Menzel 2002; Stone et al. 2002; Griffith et al. 2002; Post et al. 2003	Earlier spring thaw and a longer growing season could likely result in earlier parturition (Post et al. 2003) and increased calf survival (Griffith et al. 2002).
Climate	Timing of snow melt	Date of thaw	Reproductive success; Forage quality and availability	Earlier than average		Average	Later than average	Sparks and Menzel 2002; Stone et al. 2002; Griffith et al. 2002; Post et al. 2003	Earlier spring thaw and a longer growing season could likely result in earlier parturition (Post et al. 2003) and increased calf survival (Griffith et al. 2002).
Climate	Winter weather Ice	Snow fraction	Winter forage availability	Snow fraction below 80% for more than one winter month (thresholds unclear)	Snow fraction below 80% for one winter month	Snow fraction below 90% for one winter month	Snow fraction over 90% for all winter months	Hansen et al. 2011	Icing or rain on snow events can harden the snow pack and restrict access to forage
Climate	Winter Weather Snow depth	Snow depth	Energy expenditure; Forage availability	Above average		Average	Below average	Joly and Klein 2011	Areas with low snow levels provide easy travel and easy access to forage.

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating				Basis for Indicator Rating	Comments
				Poor	Fair	Good	Very Good		
Climate	Insect emergence	Frost-free days	Insect harassment/ avoidance	Below average		Average	Above average	Bolduc et al. 2013	Seasonal change in daily availability of arthropods is determined by the number of frost-free days (temp. > 32°F). Earlier hatches can cause movements earlier in the season. Can also cause an increase in insect populations.
	Insect abundance	Mean daily temperature between DOT and DOF		Below average		Average	Above average	Downes et al. 1985; Witter et al. 2012; Bolduc et al. 2013	Insect abundance (pests) is directly influenced by mean daily temperature. Increased pest-insect abundance (mosquitoes, blackflies, etc.) can cause increased/altered movement of herds.
Fire	Fire frequency and extent	Fire return interval	Forage quality	< 60 years between burns	60 years between burns	180 years between burns	Unburned	Jandt et al. 2008	Lichen is often destroyed by even light burn severity wildfires. Lichens have a much longer recovery time compared to vascular plants (180 yrs until complete recovery).

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating				Basis for Indicator Rating	Comments
				Poor	Fair	Good	Very Good		
Anthropogenic	Human disturbance	Landscape condition	Land use; Caribou energy expenditure; Hunting pressure	LCM = 0 on calving grounds			LCM = 1 on calving grounds	Cronin et al. 1994	During calving, cows and calves avoid roads, even with low traffic use (<100 vehicles per day), and as a result, are not typically found within one km of the roadway. Proximity of roads to caribou ranges and migration routes increases human access and predation pressure.

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Greater White-Fronted Goose (*Anser albifrons*)

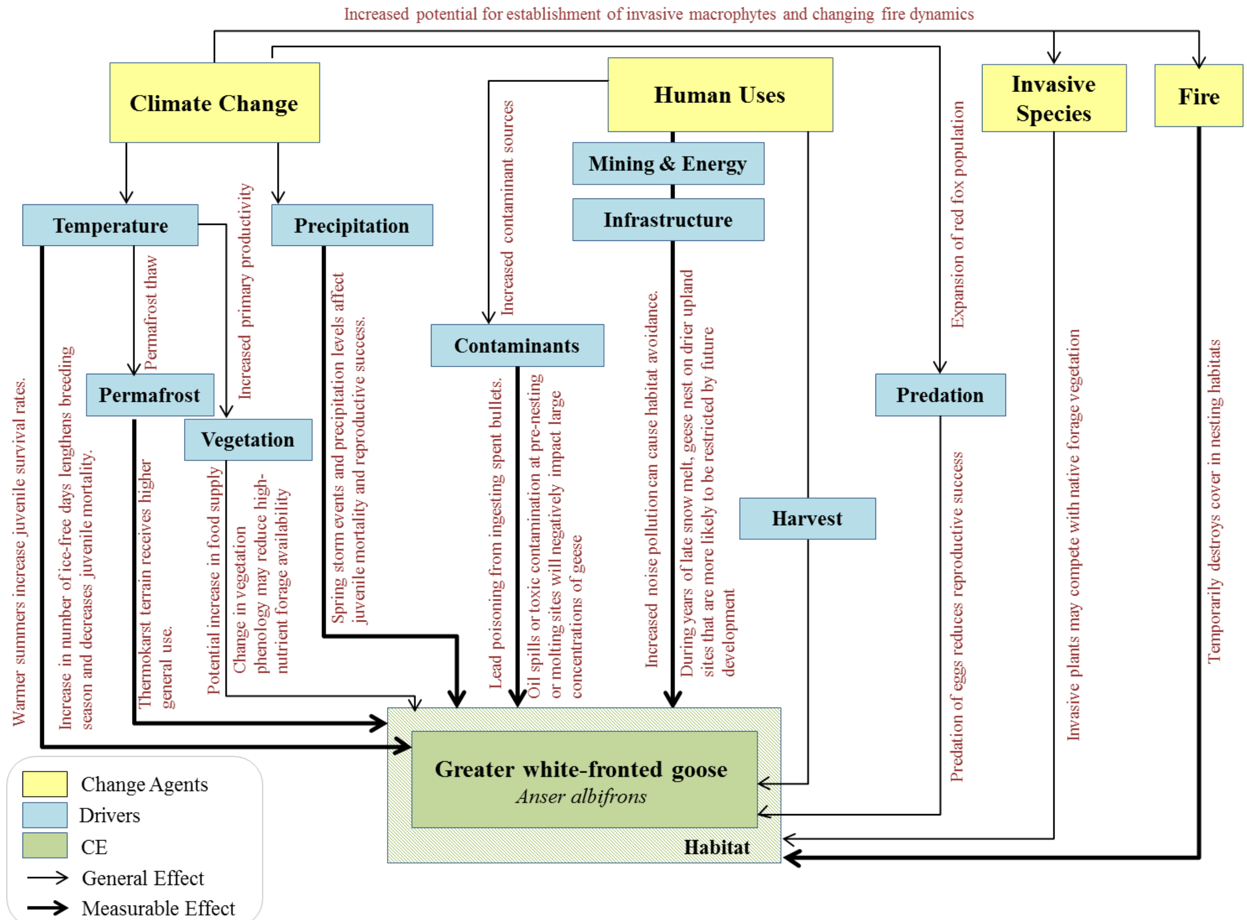
Background

The Greater white-fronted goose has a nearly circumpolar distribution. In western North America, summer breeding occurs in arctic and boreal habitats from eastern Hudson Bay to western Alaska. Geese that breed in tundra habitats differ from those that breed in boreal habitats, and interchange between the two groups is small (Marks 2013). Geese that spend summers in the arctic of Alaska and Canada, winter in Texas, Louisiana, and Mexico. Individuals live up to 26 years with late maturation and a small number of offspring per year compared to other geese (Schoen and Senner 2002).

Within the North Slope study area, Greater white-fronted geese concentrate on slough and river edges within 30 km of the Bering Sea and in wet meadows. They arrive two to three weeks before incubation, during which time they feed intensively. Primary forage consists of *Arctophila fulva* shoots and *Triglochin palustris* bulbs (Budeau et al. 1991). Breeding pairs occupy much of the western Beaufort Coastal Plain in open tundra with nest sites in dense grass, sedge, and shrubs. Common locations include slough banks, lake shores, and pingos and polygon ridges near water. Areas of high breeding density include the Colville River Delta, Teshekpuk Lake Special Area, Dease Inlet and Smith Bay, west of Atqasuk, and Kasegaluk Lagoon (Schoen and Senner 2002). Incubating geese feed infrequently and primarily rely on stored energy reserves (Budeau et al. 1991).

Molting typically begins in early July. Geese select areas near lakes or river deltas that provide forage access and predator escape during this time. Many geese aggregate around Teshekpuk Lake. During molting, primary forage consists of *Arctophila fulva* and *Carex* species.

Conceptual Model



Climate Change

Warming temperatures will alter the overall phenology of the region, including earlier snowmelt and plant growth (Sparks and Menzel 2002, Stone et al. 2002). An increase in the number of ice-free days and earlier spring thaw could result in earlier goose arrival and lengthened breeding season duration, potentially decreasing juvenile mortality rates (Sargeant and Reveling 1992, Ely and Dzubin 1994, Boyd and Fox 2008). Increased primary production from earlier spring thaw and warmer temperatures will benefit geese as long as the shift in breeding season remains matched to the emergence of forage vegetation (USFWS 2008).

Increases in precipitation could lead to greater likelihood of flooding events. Flooding can cause Greater white-fronted goose nest failure. On the Yukon-Kuskokwim Delta of Alaska in 1978, 13 of 25 Greater white-fronted goose nests flooded were destroyed, while only 3 out of 19 nests that had not been flooded were destroyed (Ely and Raveling 1984).

Permafrost melt may result in increased thermokarst terrain that may provide additional preferable habitat for Greater white-fronted geese.

Greater white-fronted geese appear to be prospering under recent climate-change-induced habitat modifications on both coastal and interior portions of the Arctic Coastal Plain. Population size of the Greater white-fronted goose has increased seven-fold in northern Alaska since 1980, while Black brant (*Branta bernicla nigricans*) and Canada goose (*Branta canadensis*) populations have remained constant in this area (Flint et al. 2008).

Fire

Increased fire may temporarily reduce quality of breeding habitat by destroying cover in nesting habitats (Hoffpauier 1968).

Invasive Species

Invasive plant species may compete with native forage species in the future. However, invasive species are currently limited in the North Slope study area and are not likely to expand enough within the next 50 years to have major impacts on Greater white-fronted goose habitat.

Anthropogenic Uses

Greater white-fronted geese are loyal to breeding and molting sites, which may hinder a population's ability to relocate if breeding or molting sites are negatively impacted or destroyed by development. Because geese concentrate at pre-nesting and molting sites, the effects of severe but rare local disturbance events, such as oil spills or toxic contamination, will likely have large negative impacts on populations (Schoen and Senner 2002). During years of late snow melt, geese nest on drier upland sites (Ely and Raveling 1984) that are more likely to be restricted by future development. Greater white-fronted geese are sensitive to machine noise (Barry and Spencer 1976 *in* Ely and Dzubin 1994) and aircraft disturbance (Derksen et al. 1979) which can result in habitat avoidance.

Some evidence has suggested that predators of tundra-nesting birds, primarily ravens (*Corvus corax*), become more numerous in areas of human development because of the presence of additional food sources and artificial nesting/denning sites. While recent improvements to waste handling procedures associated with oil field infrastructure have likely dampened this effect in oil fields (Liebezeit et al. 2009), this may still be a concern in areas of other development.

Harvest and Predation

Greater white-fronted geese are harvested by subsistence users on the North Slope. Because Greater white-fronted geese arrive relatively early in spring compared to other geese, they may receive greater subsistence hunting pressure prior to breeding.

Jaegers (*Stercorarius* spp.), large gulls (*Larus* spp.), and Ravens (*Corvus corax*) prey upon nests of Greater white-fronted geese. Gyrfalcon (*Falco rusticolus*), mink (*Mustela vison*) and large carnivorous mammals predate on both eggs and geese (Schoen and Senner 2002). Arctic foxes are present in high densities in the northern portion of the NPRA (Bart et al. 2013) and exert high predation pressure on tundra nests during nesting season, including those of the Greater white-fronted goose (Stickney 1991). Predation by red foxes (*Vulpes vulpes*) may increase if the climate becomes more suitable for the expansion of the red fox population (Liebezeit et al. 2012).

Attributes and Indicators

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating: Poor	Fair	Good	Very Good	Basis for Indicator Rating	Comments
Climate	Timing of snow melt	Date of thaw	Breeding commencement and success	Later than average		Average	Earlier than average	Ely and Dzubin 1994; USFWS 2008	Late snowmelt results in delayed breeding; change in vegetation phenology may reduce availability of high-quality geese forage.
	Spring precipitation	April + May total precipitation.	Reproductive success	Above average		Average	Below average	Boyd and Fox 2008	Increased precipitation results in decreased reproductive success.
	Summer temperature	Mean ambient temperature (June, July, August)	Forage availability; Juvenile survival	Cooler than average		Average	Warmer than average	Boyd and Fox 2008	Warmer than average summers result in increased juvenile survival rates; and increased forage production.
	Permafrost	Permafrost melt: areas of transition from MAGT < 0C to >1 C	Breeding habitat		MAGT < 0C		MAGT > 1C		Increased thermokarst terrain receives higher general use by geese.
Fire	Fire frequency	Fire return interval	Breeding habitat	High return interval			Low return interval	Hoffpauier 1968	Increased fire may temporarily reduce quality of breeding habitat by destroying cover in nesting habitats.

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating				Basis for Indicator Rating	Comments
				Poor	Fair	Good	Very Good		
Anthropogenic	Noise disturbance	Proximity of habitat to oil and gas development, transportation corridors and airports	Breeding habitat	< 5km		> 5km		Barry and Spencer 1976 in Ely and Dzubin 1994; Derksen et al. 1979	Greater white-fronted geese are sensitive to machine noise (within 5km of nesting) which can result in habitat avoidance. Aircraft disturbance can lead to habitat avoidance at breeding/nesting sites.
	Predation pressure	Proximity of breeding habitat to industrial locations and villages	Decreased survival	< 5km		> 5km		Liebezeit et al. 2009	Risk of nest predation (by Arctic fox for example) increases within 5km of human infrastructure.
	Local disturbance events (oil spill or toxic contamination)	Proximity of habitat to contaminated sites	Breeding habitat	< 3km		>10km		Schoen and Senner 2002	Geese have a foraging range of 3-10km during breeding. Contaminant leaks within this vicinity will likely have a negative effect on individual health and reproductive success.

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating				Basis for Indicator Rating	Comments
				Poor	Fair	Good	Very Good		
Anthropogenic	Future development	Landscape condition	Poor weather refuge habitat	LCM = 0 at breeding sites			LCM = 1 at breeding sites	Ely and Raveling 1984	During years of late snow melt, geese nest on drier upland sites that are more likely to be restricted by future development.
	Lead poisoning	Concentration of hunting activity in foraging/breeding areas	Health/survival	High	Medium	Low	Zero	Frierabend 1983, Friend 1987	Lead poisoning is common from ingesting spent bullets.

Date Deficiencies

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating				Basis for Indicator Rating	Comments
				Poor	Fair	Good	Very Good		
Climate	May storm events	*No measureable indicator available*	Juvenile mortality	Numerous storms > 2 day duration	Few storms 1 - 2 day duration	Few storms < 1 day duration	No storms	Ely and Dzubin 1994	Spring storm events can cause juvenile mortality due to low lipid reserves that last a max. of 1-2 days.

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Raptor Concentration Areas

Background

Species included for the Raptor Concentration Areas CE are: Gyrfalcon (*Falco rusticolus*), Peregrine falcon (*Falco peregrinus tundrius*), and Rough-legged hawk (*Buteo lagopus*). All three species share similar habitats in arctic Alaska, but differ in seasonal distribution and prey preferences. Primary habitats include cliffs in riparian areas along river drainages and major tributaries. As top trophic-level predators, changes in their status could be indicative of large-scale ecosystem changes.

The Gyrfalcon is the largest falcon species and the most northern diurnal raptor. It is migratory with a circumpolar distribution, including summer breeding sites in Alaska. Individuals are typically present on their breeding grounds from March to September (see Booms et al. 2008 for review) however, there is evidence for winter occupation of nest sites in Alaska (Cade 1960) and other northern regions (Platt 1976, Kuyt 1980, Norment 1985). They lay one clutch (averaging 3.7 eggs; Booms et al. 2008) per year which is incubated for approximately 35 days (Platt 1977). Pairs may not breed every year, depending on prey availability (Cade 1960, Nielsen and Cade 1990). The Gyrfalcon's primary prey is the ptarmigan (*Lagopus* spp.) (Booms et al. 2008). Additional prey items may include arctic ground squirrels (*Spermophilus parryii*) (Poole and Boag 1988), and a variety of other bird species including passerines and geese (Booms et al. 2008). Foraging range during breeding is approximately 12–15 km from nest site (Palmer 1988).

The Peregrine falcon ranges throughout much of the world as either a seasonal migrant or resident. Peregrine falcons that breed in arctic Alaska spend winters in Central and South America (Liebezeit et al. 2012). The principle nesting area in the North Slope region occurs along the Colville River drainage (including major tributaries such as the Etivluk, Oolamnagavik, Killik, and Chandler rivers) and the Sagavanirktok River (APFRT 1982). Individuals are typically present on their breeding grounds from mid-April/mid-May to mid/late August (APFRT 1982). They lay one clutch (averaging 3 eggs) per year (Cade et al. 1968, Wright and Bente 2001), which is incubated for 33 to 35 days (White et al. 2002). Peregrine falcons prey primarily on bird species including passerines, shorebirds, and ducks (Mindell and Craighead 1981, *reviewed in* White et al. 2002). Foraging range during breeding is approximately 8 km (Brown and Amadon 1968).

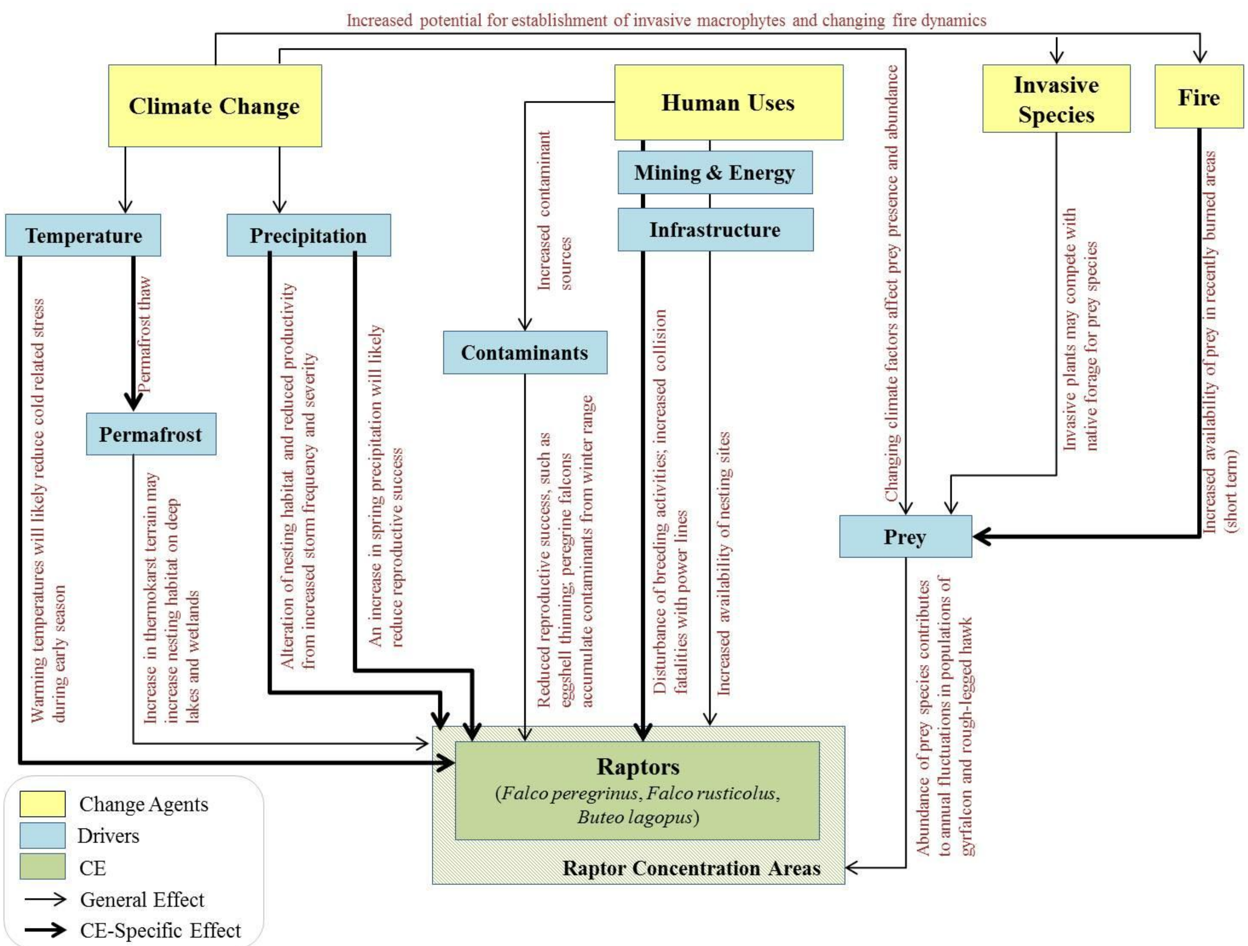
The Rough-legged hawk is a migratory species that breeds in the circumpolar arctic and subarctic, and winters in the temperate northern hemisphere. It is the most abundant and wide-spread cliff-nesting raptor in the North Slope study area (Ritchie et al. 2003). They lay one clutch (averaging 3–4 eggs) per year (Swem 1996, Kessel 1989), which is incubated for a minimum of 32 days (Parmelee et al. 1967, Cramp and Simmons 1980). In arctic Alaska, the Rough-legged hawk preys primarily on small mammals such as lemmings and voles (Bechard et al. 2002). Foraging range during breeding is approximately 3–7 km (Cannings 2002).

Nesting sites for all three species in arctic Alaska are primarily found on shale banks, mud or sand banks, rock cliffs along river corridors, rock outcrops, scree and talus slopes, and steep escarpment faces. The Gyrfalcon often uses nest sites that have been established by other species (Liebezeit et al. 2012), the

Peregrine falcon exhibits high interannual nest fidelity to nests they have built, and the Rough-legged hawk build new nests each year. Nesting sites, and therefore raptors, are most common in the Brooks Foothills, with less suitable habitat in the Brooks Range and the Beaufort Coastal Plain. Raptors nesting in the Brooks Range are primarily Gyrfalcons (Mindell et al. 1987).

Diversity of food habits vary annually for the three raptor species. Annual fluctuations in the population sizes of Gyrfalcon and Rough-legged hawk in arctic Alaska are linked to the abundance of primary prey species, which are residents of the arctic environment (Mindell et al. 1987). Synchronous population cycles have been documented between Willow ptarmigan (*L. lagopus*) and Gyrfalcon, although the regularity of Willow ptarmigan cycles may be faltering (Mossop 2011). Peregrine falcon populations appear to be more stable from year to year, likely because peregrines primarily consume migratory bird species, whose populations are less affected by local conditions, and therefore less volatile than populations of resident species (Mindell et al. 1987).

Conceptual Model



Climate Change

Predicted impacts of climate change on cliff-nesting raptors are largely unknown. Warming climate may reduce annual population variability in Rough-legged hawk, and likely in Gyrfalcon (Mindell et al. 1987). Warming temperatures may reduce cold related stress during early season, however, an increase in frequency and severity of spring storms will likely reduce reproductive success for raptors (Cade et al. 1971, Liebezeit et al. 2012).

Climate change has the potential to alter populations of important prey species. In the Yukon Territory, population cycles of Willow ptarmigan (a major prey item for Gyrfalcon) have plateaued in recent years, likely a consequence of climatic changes (see Willow ptarmigan section). Concurrent with observed changes in the population cycling of Willow ptarmigan, the timing of Gyrfalcon nesting has moved later in spring and fewer nest sites have been observed. The lack of recent peaks in ptarmigan population cycles, possibly caused by the increasing frequency and severity of spring storm events, has likely removed peaks in Gyrfalcon reproduction that have historically boosted Gyrfalcon population during ptarmigan population troughs (Mossop 2011). For the Peregrine falcon, higher daily temperature and more frost-free days directly affect insect abundance (Bale et al.2002, Bolduc 2013) and therefore health and abundance of insectivorous birds (Peregrine falcon prey).

An increase in thermokarst terrain may increase suitable nesting habitat outside of river corridors on deep lakes and wetlands. An increase in frequency and severity of erratic weather events has the potential to cause heavy rains that may influence productivity during incubation and brood rearing (Ontario Peregrine Falcon Recovery Team 2010).

Fire

The impact of fire and its potential increase in frequency and severity with a warming climate is unknown. Due to their high mobility, fire-related mortality of adult raptors is likely low. Nestling mortality is potentially higher because nestlings are unable to flee approaching fire (Luensmann 2010). Because these birds nest on cliff faces, rock outcrops, and similar sites, the potential for damage to nesting sites or nestling mortality is low but possible if vegetation on the nest ledge catches fire. Fire may threaten nests at the ground level amongst dense vegetation (Luensmann 2010).

Bird diversity and small mammal populations will likely temporarily increase in recently burned areas, as these prey species are attracted to abundant new vegetative growth in the months following fire (Luensmann 2010, Liebezeit et al. 2012). In New Mexico and southern California, abundant prey attracted Golden eagles (*Aquila chrysaetos*) and Peregrine falcons to recently burned areas (Lehman and Allendorf 1989).

Invasive Species

Invasive species are currently limited in the North Slope study area and are not likely to expand enough within the next 50 years to have major impacts on cliff-nesting raptor habitat or prey.

Anthropogenic Uses

Because Peregrine falcons and much of their prey are migratory, they are exposed to organochlorine and other contaminants in temperate and tropical wintering habitats. As a result, contaminants are more highly concentrated in the eggs of Peregrine falcons than in eggs of Gyrfalcons or Rough-legged hawks (Thomas et al. 1992). Pesticide use outside of Alaska contributed to declines in breeding populations of Peregrine falcons in Alaska in the 1960s and 1970s (Mindell et al. 1987). Contaminants that cause thinning of egg shells especially reduce the reproductive success of Peregrine falcons. New and emerging chemicals may pose potential exposure and bioaccumulation problems and threats such as embryo mortality, reduced fertility, suppression of egg formation and impaired incubation and chick rearing behaviors (Fry 1995, Ontario Peregrine Falcon Recovery Team 2010).

Increased anthropogenic uses and noise disturbances may disturb breeding activities and increase failed nesting occurrences of raptors, although studies are not conclusive (Peregrine falcon, Ritchie et al. 1997, Palmer et al. 2003). Increased development, especially of elevated infrastructure such as power lines, will increase collision fatalities. Occasionally, raptors nest on, and hunt from human infrastructure (Ritchie 1991, Liebezeit et al. 2012), however, the impact of these activities on raptor populations is likely negligible.

Harvest and Predation

Raptors are not harvested for subsistence, are not hunted recreationally, and do not have natural predators.

Attributes and Indicators

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating				Basis for Indicator Rating	Comments
				Poor	Fair	Good	Very Good		
Climate	Mean daily temperature	Mean daily temperature between DOT and DOF	Insect/prey availability; reproductive success	Below average		Average	Above average	Cade et al. 1971; Bale et al. 2002; Liebezeit et al. 2012; Bolduc 2013	Daily temperature and frost-free days directly influence arthropod abundance, which influences health and abundance of insectivorous birds (peregrine falcon prey). Mean temperature and season length also affects chick survival and reproductive success.
	Frost-free days/Season length	Cumulative days with temps above 0 °C (Days between DOT and DOF)		Below average		Average	Above average		
	Spring temperature	Mean daily temperature in May and June	Nesting success and chick survival	Below average		Average	Above average	Cade et al. 1971; Liebezeit et al. 2012	Cold, wet springs can increase egg and chick mortality
	Spring precipitation	Total precipitation for May and June		Below average		Average	Above average		
	Thermokarst establishment	Permafrost melt: areas of transition from MAGT < 0C to >1 C	Foraging habitat	MAGT < 0C			MAGT > 1C	Martin et al 2009	Permafrost thaw and thermokarst development could create foraging habitat.

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating				Basis for Indicator Rating	Comments
				Poor	Fair	Good	Very Good		
Climate	Fire frequency	Fire return interval	Prey abundance	Unburned			High fire frequency	Lehman and Allendorf 1989; Luensmann 2010; Liebezeit et al. 2012	Bird diversity and small mammal populations will likely temporarily increase in recently burned areas, as these prey species are attracted to abundant new vegetative growth in the months following fire
Anthropogenic	Noise disruption	Landscape condition	Breeding disturbance	LCM = 0 within 15 km of breeding habitat	LCM < 1 within 10 - 15 km of breeding habitat	LCM <1 within 12 km of breeding habitat	LCM = 1 within 15 km of breeding habitat	Palmer 1988 (Gyrfalcon foraging range); Brown and Amadon 1968 (Peregrine falcon foraging range); Cannings 2002 (review of Rough-legged hawk foraging range); Oregon Department of Transportation 2007	Human activity (including noise, recreational activities, and vehicle traffic) and development near nesting sites can deter and disturb breeding activities, cause nest abandonment, and destroy potential nesting habitat. Foraging range for Gyrfalcon, Peregrine falcon and Rough-legged hawk are 12 - 15 km, 8 km and 3-7 km respectively.

Data Deficiencies

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating				Basis for Indicator Rating	Comments
				Poor	Fair	Good	Very Good		
Climate	May storm events	*No measureable indicator available*	Reproductive success	Above average			Below average	Ontario Peregrine Falcon Recovery Team 2010; Liebezeit et al. 2012	Clutch size may be reduced in years of climatic severity

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Arctic Fox (*Vulpes lagopus*)

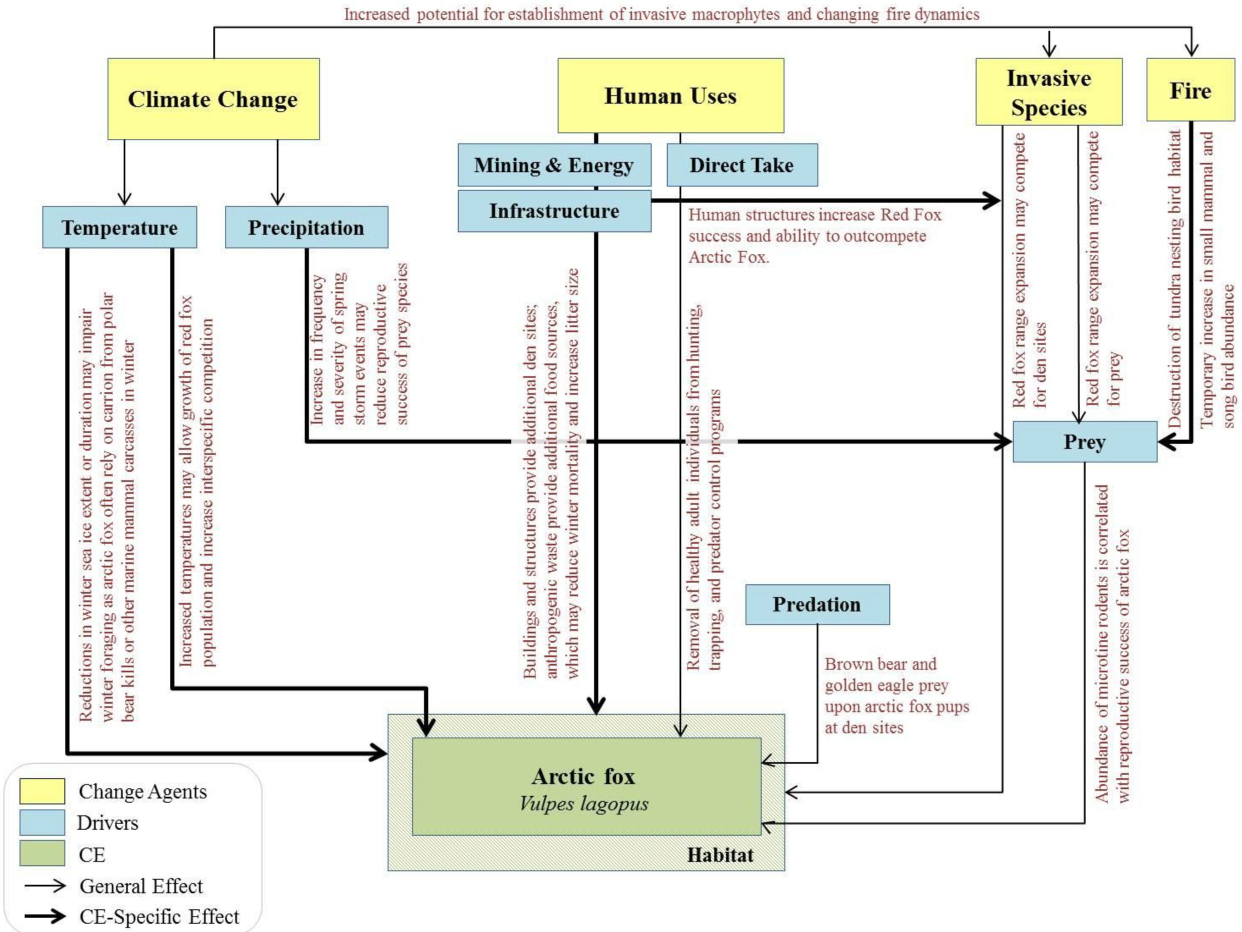
Background

The Arctic fox is a medium-sized predator with a circumpolar distribution. In Alaska, Arctic fox occupies the Aleutian Islands, to which they were introduced, the Kuskokwim River Delta, Bering Sea Islands, and the Beaufort Coastal Plain. Arctic fox are well adapted for survival in the extreme cold of arctic winters. Breeding occurs in March or April and gestation lasts roughly 52 days. Arctic fox den sites are used each year, though not necessarily by the same breeding pair. Den sites are typically located on mounds, low hills, and low ridges that are drier than surrounding lowlands with sandy soils (Burgess 2000). Dens are selected based on proximity to good foraging areas and distance from other occupied dens (Szor et al. 2008).

Arctic fox primary prey preferences change between seasons. For much of the year, Arctic fox primarily consume lemmings, voles, and other small mammals (Burgess 2000). On the Siberian arctic coast, the diet of Arctic fox consists primarily of the closely related Siberian brown lemming (*Lemmus sibiricus*). Arctic fox populations fluctuate annually, with peaks in abundance occurring every 3 to 4 years in relation to microtine rodent abundance, specifically Nearctic brown lemming (*Dicrostonyx trimucronatus*; Angerbjörn et al. 1999). Fluctuations in lemming abundance generate oscillations in Arctic fox productivity and, consequently, in the predation pressure imposed by Arctic fox on secondary prey species such as geese and shorebirds (Gauthier et al. 2004). During winter, foxes may also range out onto sea ice to consume carrion from polar bear kills and other marine mammal carcasses (Burgess 2000, Pamperin et al. 2008).

During tundra bird nesting season, Arctic fox exhibit a strong preference for eggs and consume eggs even in years when microtine rodents are abundant (Stickney 1991, Bantle and Alisauskas 1998). Egg foraging is most successful in wet meadow habitats where ducks and shorebirds nest in high numbers. These birds are not able to successfully defend against Arctic fox. Arctic fox foraging in pingo habitats also occurs, but nest sites are typically less dense and are primarily occupied by geese, which are better able to defend nest sites.

Conceptual Model



<u>Climate Change</u>

The southern range extent of Arctic fox on the North Slope is likely determined by the northern range extent of red fox (*Vulpes vulpes*) (Hersteinsson and Macdonald 1992). Red fox are larger than Arctic fox but are currently uncommon outside of river corridors on the Beaufort Coastal Plain. Warming temperatures may increase the suitability of red fox habitat on the Beaufort Coastal Plain which could potentially lead to their expansion in the ecoregion. Where their ranges overlap, the two fox species may compete for resources with the red fox being more dominant (Pamperin et al. 2006). This would likely cause increased competition for den sites and the potential for reduction in the Arctic fox population (Burgess 2000, Szor et al. 2008).

A reduction in winter sea ice extent or duration may negatively impact Arctic fox by limiting their ability to forage for the carrion of polar bear kills and other marine mammal carcasses in winter. This could potentially reduce winter survival and reproductive success in years where small mammal abundance is low (Pamperin et al. 2008).

<u>Fire</u>

Bird diversity and small mammal populations will likely increase temporarily in recently burned areas, as these prey species are attracted to abundant new vegetative growth in the months following fire

(Luensmann 2010, Liebezeit et al. 2012), resulting in increased prey abundance for Arctic fox. However, increased fire may also temporarily reduce quality of breeding habitat for tundra-nesting birds by destroying cover in nesting habitats (Hoffpauier 1968) and thereby reducing Arctic fox prey.

Invasive Species

Invasive plant species may compete with native forage in the future. However, invasive species are currently limited in the North Slope study area and are not likely to expand enough within the next 50 years to have major impacts on Arctic fox.

Anthropogenic Uses

When undisturbed, Arctic fox coexist with and sometimes are attracted by human infrastructure and development. Artificial food sources, such as improperly disposed waste, are consumed by Arctic fox. Garbage dumps at villages can attract large numbers of foxes in winter (Burgess 2000) and industrial infrastructure may provide additional den sites (Burgess et al. 1993). Aerial surveys have shown that Arctic fox populations are greater in the northern portion of the NPRA where there are higher concentrations of tundra-nesting birds. In addition, oil field infrastructure appears to have little effect on aquatic bird (Arctic fox prey) or Arctic fox densities in the central portion of the Prudhoe Bay Oil Field (Bart et al. 2013). If human infrastructure does not deter Arctic fox presence, increased human populations due to development may result in increased hunting pressure due to increased accessibility. In addition, human infrastructure assists establishment of Red fox populations that may outcompete currently established Arctic fox populations (A. Stickney, pers comms; Pamperin et al. 2006).

Harvest and Predation

Arctic fox are hunted/trapped for fur but are not harvested for subsistence purposes. Predator control programs reduce Arctic fox populations in the North Slope study area. Brown bears (*Ursus arctos*) and Golden eagles (*Aquila chrysaetos*) prey upon Arctic fox pups at den sites (Burgess 2000).

Attributes and Indicators

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating				Basis for Indicator Rating	Comments
				Poor	Fair	Good	Very Good		
Climate	Annual temperature	Annual mean temperature	Competition with Red fox	Above average		Average	Below average	Hersteinsson and Macdonald 1992; Pamperin et al. 2006	Warmer temperatures are associated with northern expansion of Red fox range. Red fox outcompete Arctic fox for prey and denning sites.
	Snow depth	Snow depth	Prey availability	Above average		Average	Below average	Duchesne et al. 2011	Deeper snow impedes predation on Brown lemming.
Fire	Fire frequency	Fire return interval	Prey availability	High return interval			Low return interval	Hoffpauier 1968	Fire may temporarily reduce quality of breeding habitat for tundra-nesting birds (Arctic fox prey) by destroying nesting habitat cover.
				Low return interval			High return interval	Luensmann 2010; Liebezeit et al. 2012	Small birds and mammals are attracted to abundant new vegetative growth in the months following fire resulting in increased prey abundance for Arctic fox.

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating				Basis for Indicator Rating	Comments
				Poor	Fair	Good	Very Good		
Anthropogenic	Increased human population	Landscape condition	Increased hunting pressure; Increased Red fox establishment success	LCM = 0 within 2 km of existing Arctic fox denning sites.	LCM < 1 within 2 - 4km of existing Arctic fox denning sites.		LCM = 1 within 4 km of existing Arctic fox denning sites.	Burgess et al 1993; Burgess 2000; Bart et al. 2013; Hammerson and Cannings 2004 (review of Red fox home range size)	Development does not have a direct impact on Arctic fox or prey species; however, increased human presence may result in increased hunting pressure since Arctic fox are not deterred from human-use areas. New infrastructure without human inhabitants can create denning sites for Arctic fox. Red fox home range size is 2-4 km, therefore human infrastructure (providing food/den sites for Red fox) within 2-4 km of Arctic fox den sites could be detrimental.

Data Deficiencies

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating				Basis for Indicator Rating	Comments
				Poor	Fair	Good	Very Good		
Climate	May storm events	*No measureable indicator available*	Reproductive success	More than avg.			Less than avg.	Ely and Dzubin 1994	Severe spring weather can decrease reproductive success of prey items.
	Winter sea ice	*Beyond scope of study*	Winter survival in rodent poor years; Increased genetic divergence	Above average		Average	Below average	Noren et al. 2011	Sea ice is important for maintaining connectivity in Arctic fox populations; important for foraging

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Lapland longspur (*Calcarius lapponicus*)

Background

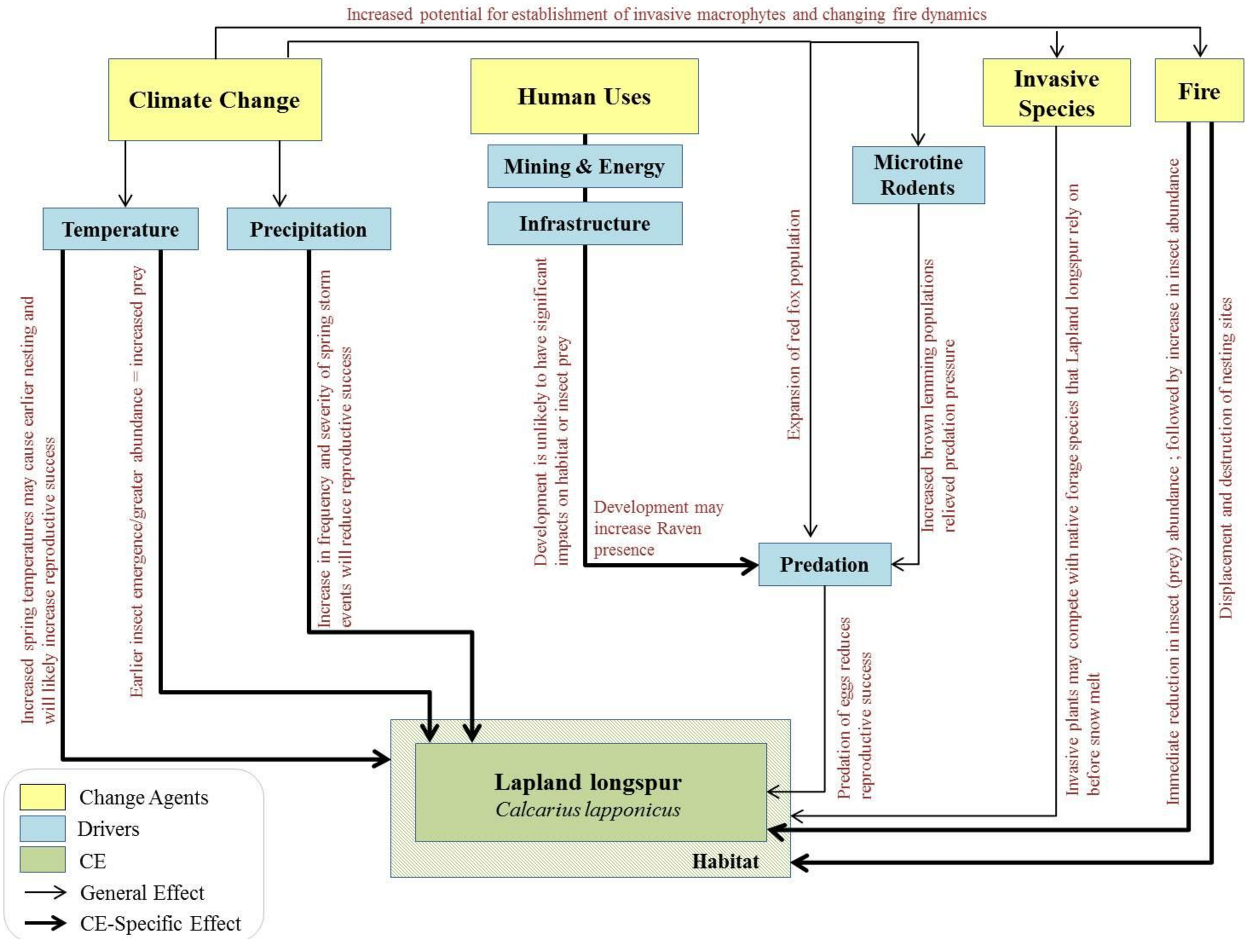
The Lapland longspur is a migratory species that summers in circumpolar arctic and subarctic regions, and winters further south in the temperate zones of Japan, Korea, China, central Eurasia and the North Seacoasts, and across continental North America. In Alaska, the Lapland longspur breeds from the Aleutian and Bering Sea Islands, through western Alaska and north across the Arctic with high nesting densities associated with the Alaskan coastal plain (Custer and Pitelka 1977, Liebezeit et al. 2011). Nest sites are often in dry/moist tundra near tussocks, and less frequently in wetter tundra habitats (Hussell and Montgomerie 2002). Nest sites are also found in alpine habitats in the interior Brooks Range. The Lapland longspur is the most abundant passerine breeder on the North Slope of Alaska.

Birds arrive at breeding sites on the north coast of Alaska during the third week of May (*reviewed in* Hussell and Montgomerie 2002) and nesting occurs in early June directly after snow melt allowing for young to achieve independence prior to the end of insect emergence (particularly adult rane flies). Average clutch size is approximately 5 eggs and adults feed larval insects to their young (Custer and Pitelka 1977). Severe spring weather can decrease reproductive success (Wingfield and Hunt 2002).

Seeds, especially on exposed grasses, are a major component of Lapland longspur diet when snow still covers the ground. After snow melt, Lapland longspur primarily consume larval dipteran flies until July when adult dipteran flies emerge. During the breeding season they typically forage in a wide range of habitats on a variety of invertebrates but also consume seeds and other vegetative matter (Hussell and Montgomerie 2002). Preferred foraging habitat often consists of drier upland sites but Lapland longspur also forage in wet tundra. In August, saw-fly larvae are the most important food source (Custer and Pitelka 1978).

The Lapland longspur is considered a keystone species of arctic ecosystems because of its relation to vegetation stratigraphy, its abundance reflecting the height, nature and extent of willow scrub, and because of its dependence on the phenology and abundance of invertebrate prey and the effects that they have on prey and predator populations (avian and mammalian carnivores) (ATBMP 2013). This species is common throughout the Arctic wherever suitable habitat exists; thus, its disappearance from key areas would likely have ecosystem consequences, both as a consumer of arthropods and prey to generalist predators such as Arctic foxes, but also as prey to specialist predators, such as Peregrine falcons, where declines could have local consequences (ATBMP 2013).

Conceptual Model



Climate Change

Passerine breeding activity in the Arctic is closely linked with emergence of invertebrate prey (Fox et al. 1987). Insect presence and abundance is directly influenced by mean ambient temperature and frost-free days (Bolduc et al. 2013), therefore, climate change could affect prey abundance and/or shift the emergence date of insects.

Onset of nesting is timed with snowmelt (Custer and Pitelka 1977). Warmer spring temperatures expedite snowmelt and create snow-free areas earlier, which will likely result in earlier nesting dates. Earlier nesting dates may result in increased reproductive success (Liebezeit et al. 2012), as long as the shift in breeding season remains matched to the emergence of surface active insects. The Lapland Longspur, appears to have adjusted nest initiation in response to climate warming over the last 10 years (Liebezeit et al. 2012), but it is unknown whether this result can be generalized. An increase in frequency and severity of spring storm events could have negative implications for reproductive success. Clutch size may be reduced in years of climatic severity (Fox et al. 1987).

Extreme weather events may change (i.e., depress) the activity patterns and availability of surface-active insects. A decrease in insect prey abundance during reproduction may have negative reproductive consequences. Alternatively, warmer ambient temperatures and additional frost-free days could cause increased insect outbreaks, providing additional food resources.

Fire

Lapland longspurs are the dominant nesting bird within sedge tussock-shrub tundra, which covers more area than any other plant community in northwestern Alaska (Wright 1981). Historically, fire in sedge tussock-shrub tundra has resulted in a reduction of breeding Lapland longspurs the following year (Wright 1981). The following activities were indicated as factors and mechanisms for reduced bird abundance immediately following a fire: direct burning deterred settling of birds; males established larger breeding territories post fire; reduction of prey abundance; and elimination of nest sites from direct burning (Wright 1981). Long-term post-fire effects are not reported.

Invasive Species

Invasive vegetation species may compete with native forage vegetation in the future. However, invasive species are currently limited in the North Slope study area and are not likely to expand enough within the next 50 years to have major impacts on Lapland longspur habitat.

Anthropogenic Uses

Some evidence has suggested that Ravens (*Corvus corax*) become more numerous in areas of human development because of the presence of additional food sources and artificial nesting/denning sites. While recent improvements to waste handling procedures associated with oil field infrastructure have likely dampened this effect in oil fields (Liebezeit et al. 2009), this may still be a concern in areas of other development. Ravens are known to prey on Lapland longspur nestlings (Fox et al. 1987, Støen et al. 2010).

Harvest and Predation

Lapland longspur does not receive major harvest pressure.

The degree of nest predation varies greatly from year to year. In years of low lemming abundance, predation by avian and mammalian predators on the Lapland longspur increases, resulting in reduced reproductive success (Custer and Pitelka 1977). Breeding pairs that lose nests to predators rarely re-nest in the same season (Wingfield and Hunt 2002). See notes about predation by Ravens in Anthropogenic uses.

Attributes and Indicators

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating				Basis for Indicator Rating	Comments
				Poor	Fair	Good	Very Good		
Climate	Timing of snow melt	Date of thaw	Reproductive success	Later than avg.			Earlier than avg.	Custer and Pitelka 1977; Liebezeit et al. 2012	Onset of nesting is timed with snow melt.
	Insect emergence and abundance	Mean temperature between DOT and DOF	Prey availability	Below average			Above average	Bolduc et al. 2013	Insect emergence and abundance are directly influenced by mean ambient temperature and the number of frost-free days.
		Number of days between date of thaw and date of freeze		Below average			Above average		
Fire	Fire frequency	Fire return interval	Prey availability; breeding habitat	High fire return interval			Moderate fire return interval	Wright 1981; Luensmann 2010; Liebezeit et al. 2012	Population reduced immediately after fire due to reduced insect (prey) abundance, displacement, damaged/burnt nest sites. Following a fire, new vegetation and insect abundance can increase bird diversity and abundance.
Anthropogenic	Human presence/raven abundance	Industrial locations and villages	Chick survival	Human development < 5 km from nesting habitat	Human development sites 5 - 10 km from nesting habitat		Human development sites > 10 km from nesting habitat	Cannings and Hammerson 2004; Leibezeit et al 2009; Støen et al. 2010	Risk of predation on passerine bird nests increases within 5 km of human infrastructure. Ravens, a common predator associated with human infrastructure have a foraging range of approx. 5 - 7 km in diameter.

Data Deficiencies

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating				Basis for Indicator Rating	Comments
				Poor	Fair	Good	Very Good		
Climate	May storm events	*No measureable indicator available*	Reproductive success	More storms than avg.			Fewer storms than avg.	Fox et al. 1987	Clutch size may be reduced in years of climatic severity
Predation	Lemming abundance	*See Brown lemming table for indicators*	Predation pressure; Breeding success	Low abundance			High abundance	Custer and Pitelka 1977; Wingfield and Hunt 2002	In years of low lemming abundance, high predation by avian and mammalian predators increases, resulting in reduced reproductive success. Breeding pairs that lose nests to predators rarely re-nest in the same season.

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Willow ptarmigan (*Lagopus lagopus*)

Background

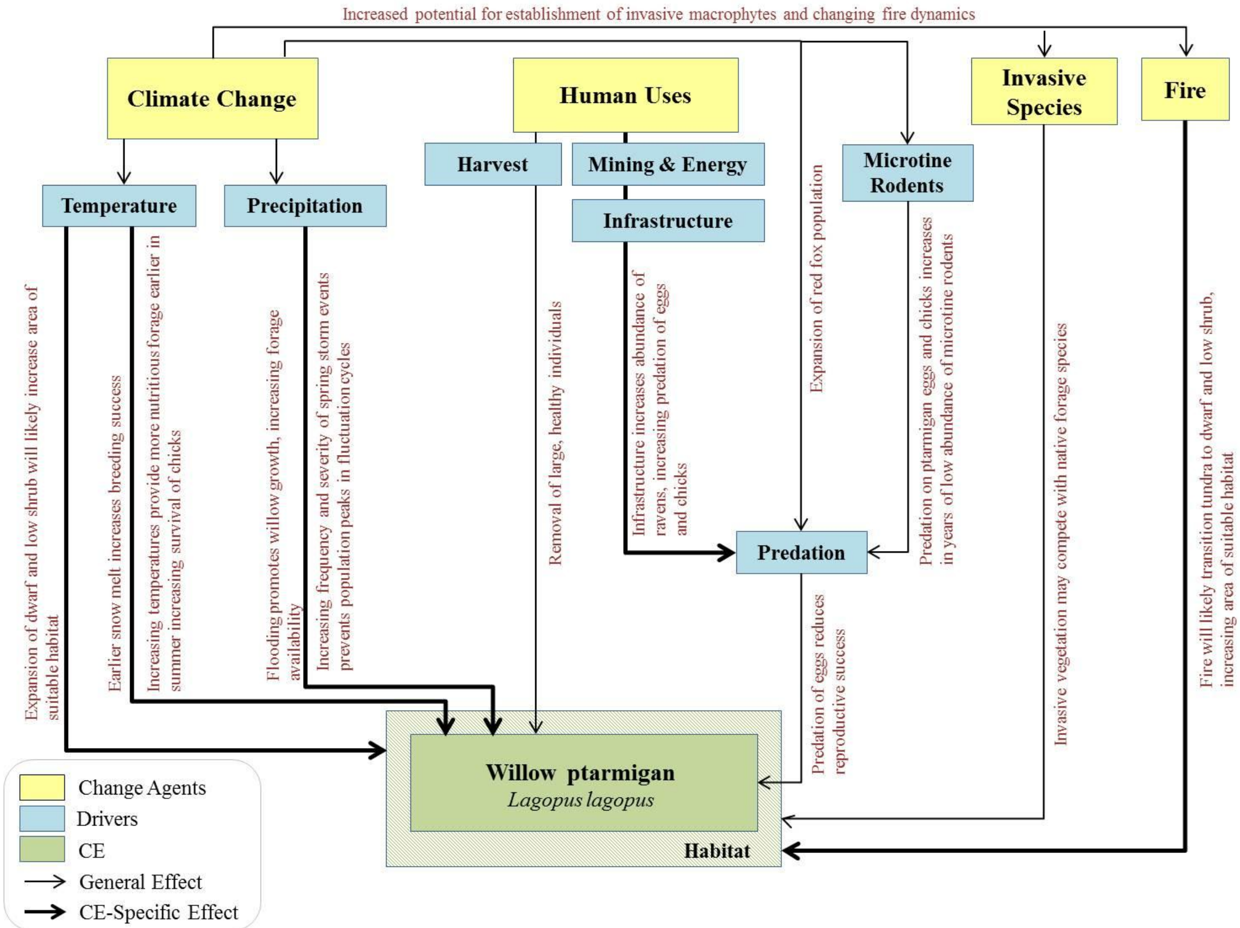
Willow ptarmigan occupy the boreal and arctic northern hemisphere, and are one of the few bird species that remain in the Arctic year-round. Ptarmigan nest on the ground after snow melt in willow and alder brush along major river corridors (Irving et al. 1967). Average clutch size is 6–10 eggs and chicks hatch in late June to early July. In the Yukon Territory, Willow ptarmigan populations fluctuate in regular ten year patterns, although population cycles have recently been disrupted (Mossop 2011).

Willow ptarmigan forage changes throughout the year. In late September, Willow ptarmigan in arctic Alaska form flocks and migrate south to mountain passes in the Brooks Range or the boreal forest of the southern Brooks Range where they primarily forage on willow buds and twigs for the winter. In April and May, ptarmigan return to arctic nesting grounds (Irving et al. 1967, Tape et al. 2010). When they arrive at breeding grounds in spring, snow still covers the ground restricting access to forage. Thus, they are forced to feed almost exclusively on taller shrub species, particularly *Salix alaxensis* (which constitutes up to 80% of their diet) (Tape et al. 2010). This level of intensive browsing reduces the number of catkins on tall, but not short willows, because the short shrubs are still buried by snow (Tape at al. 2010). Browsing of this severity slows the growth of willow shrubs and could affect shrub architecture to such an extent as to retard the greening trend or alter the snow regime—these direct effects and feedbacks are only recently being explored (Tape et al. 2010).

In June, prior to nesting, males spend much of their time defending nesting territories while females spend more time foraging. Willow catkins often remain the primary forage at this time of year. In July, adult ptarmigan forage on young willow leaves and maturing seeds. In August, *Arctous* berries become important in addition to willow leaves. Chicks feed on a variety of flowers, fruits, seeds, insects, and willow leaves (Williams et al. 1980).

Willow ptarmigan is an important prey species for Gyrfalcon and is considered a keystone species for tundra environments (Mossop 2011).

Conceptual Model



Climate Change

Expansion of dwarf and low shrub vegetation communities will likely increase the area of suitable breeding habitat available to Willow ptarmigan. Increased temperatures can provide more nutritious forage, such as inflorescences of *Bistorta vivipara*, for ptarmigan chicks earlier in summer (Williams et al. 1980).

Climate change has the potential to alter patterns of population fluctuations. For example, fluctuating population cycles of willow ptarmigan in the Yukon Territory have plateaued in recent years. While there is no evidence of overall population decline, recent population peaks are lacking. This lack of peaks may be due to the increasing frequency and severity of spring storm events (Mossop 2011). In addition, chick production has been negatively correlated with both cold spring temperatures (Wilson 2008) and the number of spring rain events prior to hatching (Steen et al. 1988).

Willow ptarmigan appear to adjust their lay dates according to snow cover, which varies annually and is dependent on spring ambient temperatures (Wilson 2008). Despite strong resilience in fecundity parameters, when snowmelt is extremely delayed, breeding success is greatly reduced (Martin and Weibe 2004).

Disturbance events such as periodic flooding of riparian areas and deposition of sediment may benefit ptarmigan by enhancing habitat suitability for early successional willows such as *S. alaxensis*. However, in the longer term, the expected invasion of trees such as poplar (*Populus balsamifera*) in riparian floodplains would be detrimental to ptarmigan (Liebezeit et al. 2012).

Fire

Fire will likely transition the tundra to dwarf and low shrub, increasing area of suitable habitat and forage for Willow ptarmigan.

Invasive Species

Invasive species may compete with native forage vegetation in the future. However, invasive species are currently limited in the North Slope study area and are not likely to expand enough within the next 50 years to have major impacts on Willow ptarmigan habitat.

Anthropogenic Uses

Some evidence has suggested that Ravens (*Corvus corax*) become more numerous in areas of human development because of the presence of additional food sources and artificial nesting/denning sites. While recent improvements to waste handling procedures associated with oil field infrastructure have likely dampened this effect in oil fields (Liebezeit et al. 2009), this may still be a concern in areas of other development. Ravens prey on ptarmigan eggs and chicks. Increased Raven abundance could potentially reduce the reproductive success of Willow ptarmigan (Støen et al. 2010). In addition, it has been shown that nest predation on Willow ptarmigan significantly increases within 5 km of human infrastructure (Pederson et al. 2011).

Harvest and Predation

Willow ptarmigan are an important subsistence species and are harvested by many communities.

Predation is the largest direct cause of nest failure for Willow ptarmigan (Wilson 2008). Willow ptarmigan are primarily predated by Gyrfalcon (Mossop 2011) and predation of eggs and chicks by other predators reduces reproductive success. Abundance of microtine rodents can affect the predation pressure that eggs and chicks receive and can therefore indirectly influence ptarmigan populations (Steen et al. 1988). See notes about Ravens under Anthropogenic uses.

Attributes and Indicators

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating: Poor	Fair	Good	Very Good	Basis for Indicator Rating	Comments
Climate	Timing of snow melt	Date of thaw (DOT)	Breeding success	Later than average			Earlier than average	Cotter 1999; Martin and Weibe 2004; Wilson 2008	Earlier snow melt can increase consistency of breeding success and earlier date of first egg. Ptarmigan begin breeding shortly after snow cover declines to 50%.
	Spring temperature	Mean temperature May	Breeding success	Below average		Above average	Average	Wilson 2008	Earlier clutches are typically larger than clutches laid later in the spring.
	Spring rain events	June total precipitation	Chick survival	Above average		Below average	Average	Steen et al. 1988; Hannon et al 1998 (review of incubation timing: late May - late June)	Increased rain levels during incubation can decrease chick production/survival. Clutch initiation begins late May/early June and chicks hatch late June.
	Early summer ambient temperature	Mean temperature June and July	Forage availability for chicks	Below average		Average	Above average	Williams et al. 1980	Increased temperatures can provide more nutritious forage, such as inflorescences of *Bistorta vivipara*, for ptarmigan chicks earlier in summer

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating				Basis for Indicator Rating	Comments
				Poor	Fair	Good	Very Good		
Climate	Changes in vegetation and habitat	Cliome shift	Forage and habitat availability			new cliome by 2060	new cliome by 2025	SNAP cliomes report	Expansion of dwarf and low shrub vegetation communities will likely increase the area of suitable breeding habitat available to willow ptarmigan.
Fire	Fire frequency	Fire return interval	Habitat suitability	Low return interval	Average return interval	High return interval	Moderate return interval		Fire will likely transition tundra to dwarf and low shrub, increasing area of suitable habitat and forage for Willow ptarmigan.
Anthropogenic	Human infrastructure	Industrial locations and villages	Chick survival	Infrastructure < 5km from nesting habitat	Infrastructure 5 - 7 km from nesting habitat	Infrastructure > 7 km from nesting habitat	Infrastructure > 10 km from nesting habitat	Cannings and Hammerson 2004; Støen et al. 2010; Pederson et al 2011	Ravens (foraging range size: 5 - 7 km) and Red fox (foraging range size: 2 - 4 km) are associated with human infrastructure and prey on Willow ptarmigan. Increased Raven and Red fox abundance will increase predation rates.

Data Deficiencies

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating				Basis for Indicator Rating	Comments
				Poor	Fair	Good	Very Good		
Predation	Lemming abundance	*See Brown lemming table for indicators*	Predation pressure; Breeding success	Low abundance			High abundance	Custer and Pitelka 1977; Wingfield and Hunt 2002	In years of low lemming abundance, high predation by avian and mammalian predators increases, resulting in reduced reproductive success.

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Nearctic brown lemming (*Dicrostonyx trimucronatus*)

Background

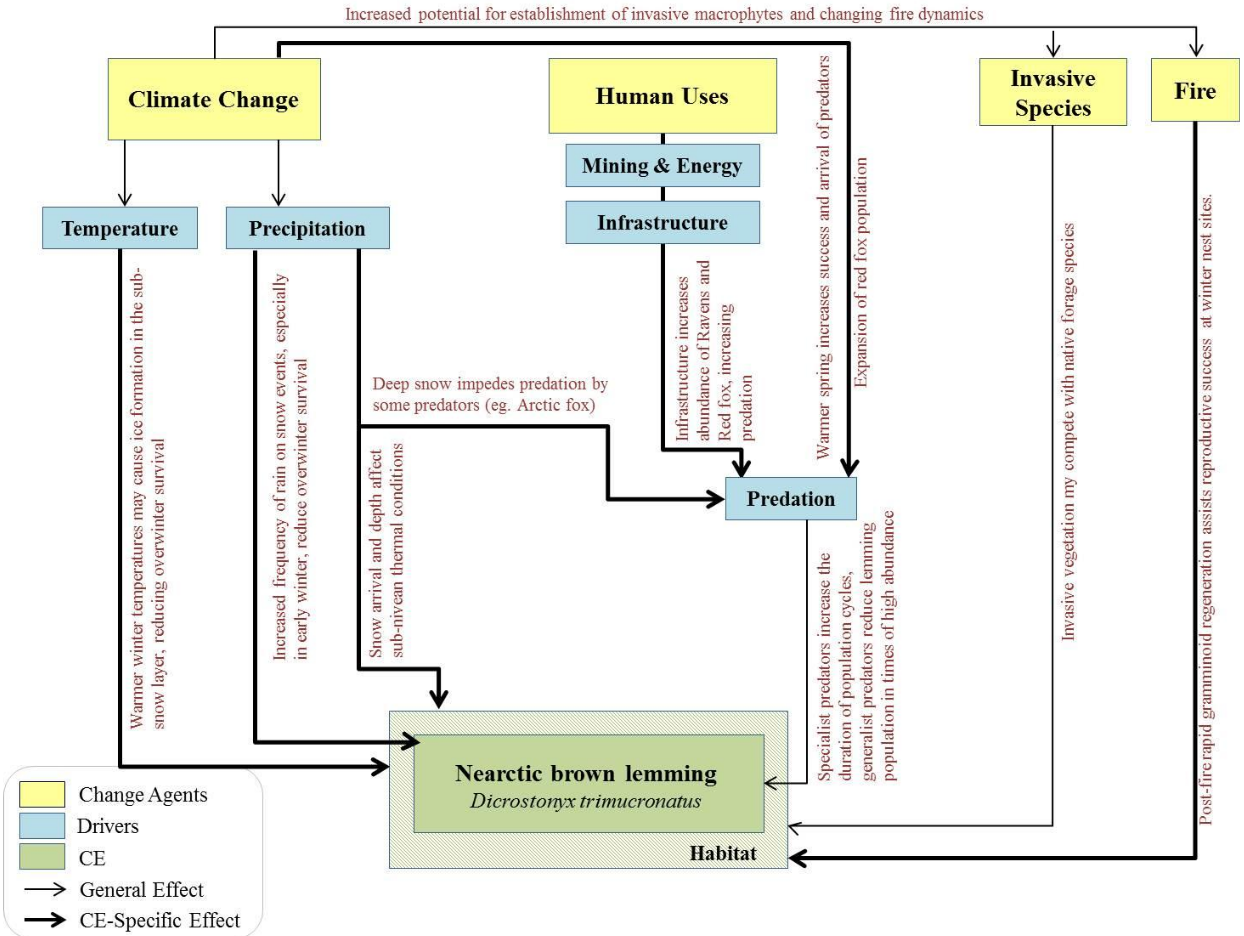
Lemmings play a keystone role in supporting arctic biodiversity due to their widespread but cyclic abundance, and their consequent role as prey for many arctic raptors and mammalian predators (McLennan et al. 2012).

Populations of Nearctic brown lemmings fluctuate cyclically and although not fully understood, typical cycling of lemming populations is thought to be the result of large population increases under favorable winter snow conditions, followed by increases in predator densities that eventually result in declines in lemming numbers (McLennan et al. 2012). In the Canadian arctic, Nearctic brown lemmings show population peaks every three or four years (Gruyer et al. 2008) while Siberian brown lemming population peaks occur every three or four years (Angerbjörn et al. 1999). Local predators such as Arctic fox (Vulpes lagopus), weasels, and Long-tailed jaegers (*Stercorarius longicaudus)* respond to lemming peak years with higher reproduction rates, and wide-ranging species such as Snowy owl (*Bubo scandiacus*) migrate across broad distances to take advantage of abundant prey (Therrien 2014).

During winter, the Nearctic brown lemming remains under the snowpack, feeding on moss shoots and leaf bases of perennial grasses and sedges (Peterson et al. 1976). In late spring and early summer when snow melt floods lowland wet meadows, brown lemmings move to uplands. Once waters recede, brown lemmings typically return to lowland wet meadows where preferred forage is abundant (Batzli et al. 1983). However, they are also found in drier upland habitats throughout the summer in years of high abundance. During summer, brown lemmings feed on mosses, grasses, and sedges (Batzli and Pitelka 1983).

Breeding occurs in mid or late July and again at the end of August in some years. Late August breeders are primarily juvenile and subadult animals that reach maturity before the onset of winter (Rodgers and Lewis 1986). Additional breeding occurs during winter under the snow which allows for recovery from low lemming population numbers and heavy summer predation. Early snow fall and adequate snow depth assists winter reproductive success. Graminoid availability at winter nest sites also contributes to reproductive success (Duchesne et al. 2011).

Conceptual Model



Climate Change

During winter, lemmings nest in areas where snow is sufficiently deep to create favorable sub-nivean thermal conditions (McLennan et al. 2012). Recent snow fence experiments on Herschel Island, in the Canadian Arctic, identified a threshold of 60 cm snow depth to create desirable thermal conditions for enhanced sub-nivean reproduction of brown lemmings and tundra voles (Reid et al. 2012).

Warm winters, low snow accumulation and winter rain events have been indicated as primary factors behind low lemming productivity and high mortality in Greenland and parts of Europe (McLennan et al. 2012), a trend sufficient to suggest the collapse of these cycles (Ims et al. 2008). Freeze thaw cycles caused by warmer winter temperatures may cause ice formation in the sub-snow layer in which Nearctic brown lemmings nest. This would likely lead to reduced overwinter survival by preventing lemmings from accessing areas of sub-snow vegetation. Similarly, increased frequency of rain on snow events, especially early in winter, will also likely affect overwinter survival (Duchesne et al. 2011, Reid et al. 2011).

Fire

Post-fire regeneration is relatively quick for graminoid species (lemming forage). Within the first year following a fire, graminoids can rebound to 100% of their pre-fire abundance and may exceed previous coverage in the following years (Jandt et al. 2008).

Invasive Species

Invasive plant species may compete with native forage vegetation in the future. However, invasive species are currently limited in the North Slope study area and are not likely to expand enough within the next 50 years to have major impacts on Nearctic brown lemming habitat.

Anthropogenic Uses

Some evidence has suggested that Ravens (*Corvus corax*) become more numerous in areas of human development because of the presence of additional food sources and artificial nesting/denning sites. While recent improvements to waste handling procedures associated with oil field infrastructure have likely dampened this effect in oil fields (Liebezeit et al. 2009), this may still be a concern in areas of other development. Ravens are known to prey on lemmings (Pitelka et al. 1955).

Harvest and Predation

Nearctic brown lemmings or not harvested or hunted.

The Nearctic brown lemming is a primary food source for many specialist predators including weasels, owls and seasonally the Arctic fox. It is also a common food source for other generalists such as predatory bird and arctic mammal species. During winter, deeper snow impedes some predators, such as Arctic fox (Duchesne et al. 2011).

Attributes and Indicators

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating				Basis for Indicator Rating	Comments
				Poor	Fair	Good	Very Good		
Climate	Winter rain events	Snow fraction December to thaw	Winter survival; Reproductive success	Snow fraction below 80% for more than one winter month	Snow fraction below 80% for one winter month	Snow fraction below 90% for one winter month	Snow fraction over 90% for all winter months	Duchesne et al. 2011, Hansen et al. 2011; Reid et al. 2011; McLennan et al. 2012	Increased frequency of rain on snow events, especially early in winter, will likely affect overwinter survival
	Snow arrival	Date of snow fall after DOF	Winter reproductive success	Later than avg.			Earlier than avg.	McLennan et al. 2012	Early and deep snow contributes to the winter reproductive success of lemmings.
	Snow depth	Snow depth	Habitat, winter survival and reproductive success	< 60 cm snow depth		60 cm snow depth	> 60 cm snow depth	Duchesne et al. 2011; McLennan et al. 2012; Reid et al. 2012	During winter, lemmings nest in areas where snow is sufficiently deep to create favorable sub-nivean thermal conditions. Snow fence experiments have identified a threshold of 60 cm snow depth to create desirable thermal conditions for enhanced sub-nivean reproduction. Deeper snow impedes some predators, such as Arctic fox, in winter.

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating				Basis for Indicator Rating	Comments
				Poor	Fair	Good	Very Good		
Fire	Fire frequency	Fire return interval	Vegetation composition	Low return interval	Moderate return interval	Average return interval	High return interval	Jandt et al. 2008	Post-fire regeneration is relatively quick for graminoid species (lemming forage). Within the first year following a fire, graminoids can rebound to 100% of their pre-fire abundance and may exceed previous coverage in the following years. Reproductive success is affected by graminoid availability at winter nest sites.
Anthropogenic	Human presence/raven abundance	Industrial locations and villages	Summer survival	Human development sites < 2 km from nesting habitat	Human development sites < 10 km from nesting habitat		Human development sites > 10 km from nesting habitat	Pitelka et al. 1955; Cannings and Hammerson 2004; Liebezeit et al. 2009	Ravens (foraging range size: 5 - 7 km) and Red fox (foraging range size: 2 - 4 km) are known to prey on lemmings, therefore increased Raven and Red fox abundance will increase predation rates.

Data Deficiencies

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating: Poor	Fair	Good	Very Good	Basis for Indicator Rating	Comments
Climate	Winter freeze/thaw cycles	# days with temperature > 0C between DOF and DOT *Daily temperature data not available*	Winter survival; Reproductive success	Frequent freeze/thaw cycles during winter			No thaw cycles during winter	Duchesne et al. 2011, Reid et al. 2011; McLennan et al. 2012	Warmer winter temperatures and freeze/thaw cycles may cause ice formation in the sub-snow layer, reducing overwinter survival.

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Appendix D: Conceptual Models for Aquatic Fine-Filter CEs

Conceptual Models, model descriptions, and attributes and indicators tables for the following terrestrial species or species assemblages:

Dolly Varden
broad whitefish
chum salmon
arctic grayling
burbot

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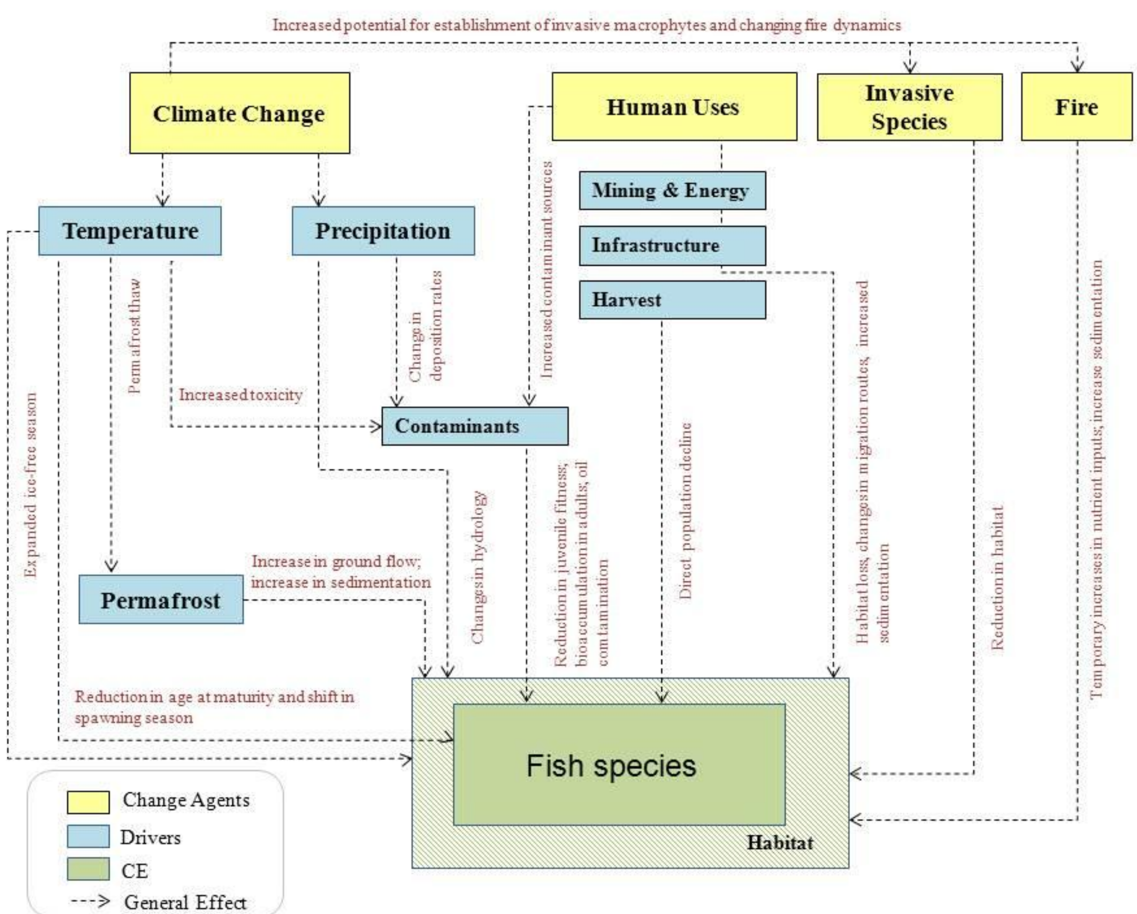
General Fish Effects

Background

Change agents (CAs) and the environmental parameters that they affect, or drivers, have specific effects on particular fish species and general effects that will impact most fish species similarly. To differentiate clearly between specific and general impacts for our fine-filter conservation elements (CEs), we propose a base conceptual model that details the general interactions between CAs, drivers, and fish and fish habitat in general. This base model forms the framework within which CE-specific effects can be understood.

Overwintering habitat is a major factor constraining fish populations on the North Slope (Schmidt et al. 1989). Ice formation during winter months (September–April) can reduce stream habitat substantially (Craig 1989) and fish are limited to overwintering habitat that provides open-water (deepwater sites in lakes and rivers) or under-ice riverine areas. Summer on the North Slope (May–August) is the critical foraging time for fish, as food is plentiful only during this period (Craig 1989).

Conceptual Model



Climate Change:

Although projected increases in air temperature are not always linearly correlated with increases in water temperature, the warming trend will result in two phenomena that have major impacts on fish habitat: increase in the duration of the ice-free season for lakes and rivers and permafrost thaw. Warmer air temperatures will increase the length of the ice-free season to a later freeze-up date and an earlier thaw date. A reduction in the length of the growing season will decrease the amount of time that fish spend overwintering and increase the amount of time that fish can spend feeding (Reist et al. 2006). As a consequence, the age at maturity for fish will decrease because individuals will be able to feed more during any single year (Brown et al. 2012). Changes in water temperatures can also alter the timing of life history events, such as sexual maturation and timing of migration and spawning, and limit preferred habitats (Reist et al. 2006). Spawning will likely shift later in the year for autumn spawners and earlier in the year for spring spawners to correspond with the time that aquatic habitats become ice-free. Additionally, warming water temperatures will have cascading effects on the susceptibility of fish to diseases and parasites (Zuray et al. 2012), increase the availability and effects of contaminants (Schiedek et al. 2007), and decrease biologically available dissolved oxygen (Ficke et al. 2007).

Increasing annual temperatures will cause a general trend of permafrost thaw on the landscape level, increasing the depth of the soil active layer and the mean annual ground temperature. Destabilized terrestrial habitats will increase erosion and runoff into river drainages. Increased stream turbidity from erosion and runoff may reduce primary production and aquatic invertebrate populations, lowering the quality of fish feeding habitat by reducing the abundance of prey species either directly or indirectly. On the other hand, permafrost thaw may increase nutrient input into aquatic habitats thereby increasing primary production and invertebrate populations (Bowden et al. 2008). Increased nutrient input will improve the quality of fish feeding habitat with the direct or indirect increased abundance of prey species (Reist et al. 2006). Effects of permafrost melt are likely to be localized, with some feeding habitat decreasing in favorability and some feeding habitat increasing in favorability. Sedimentation of gravel-substrate in streams will reduce the quality of spawning habitat for species that rely on gravel substrate to hide their eggs (Brown et al. 2012).

A predicted increase in winter precipitation could potentially increase available overwintering habitat directly (by increasing the volume of water) and indirectly through the loss of snow insulation which would reduce ice thickness. Increased precipitation could also result in increased run-off and sedimentation to fish habitat.

The combination of climate CAs and their effects on fish CEs are complex and often interconnected. Consequently, the future long-term impacts to fish CEs and aquatic habitats remain unclear.

Fire:

Fire removes stabilizing vegetation from the landscape and can result in an increase in erosion and runoff, resulting in higher sediment inputs to streams and rivers. Increased runoff has the potential to decrease both primary productivity and aquatic invertebrate populations through increased turbidity. The increases in erosion and runoff in burned areas also increase nutrient inputs to aquatic habitats (Davis et al. 2013). These effects are temporary and are limited by the re-establishment of vegetation.

Contaminants:

As water temperature increases, certain contaminants become more bioavailable (e.g., mercury) and exposure rates of contaminants to fish will likely increase. Mercury is a highly toxic metal that has negative impacts on the health of fish populations as well as wildlife and humans that consume fish. Microbial activity can convert inorganic mercury into its most toxic form, methlymercury (MeHg; Benoit et al. 2003), where it is rapidly incorporated into the food web and biomagnifies from one trophic level to the next (Ochoa-acuna et al. 2002). Warming temperatures within the NOS REA study area may further exacerbate mercury exposure in fish within this region by both releasing snowpack- and permafrost-entrained mercury, and by enhancing conditions that facilitate methylHg production (AMAP 2002).

Oil contamination is another contaminant of concern for fish species within the North Slope study area. Oil contamination has the largest impact on eggs, larvae, and juvenile fish because of their reduced capacity to leave the contaminated area.

Anthropogenic Uses:

Most development on the North Slope is related to oil and gas industries. Fish species on the North Slope can be affected by a number of factors related to development including: changes in water quality, construction of stream crossings, winter water withdrawals, and release of contaminants. Habitat alterations to stream flow or changes to underlying sediments caused by stream crossings can lead to changes in water temperature, turbidity, and dissolved ion concentrations, which in turn could have negative impacts on fish populations. Major construction, especially of roads will increase erosion and runoff leading to increased stream turbidity and sedimentation, and could introduce contaminates into fish habitats (e.g., vehicular leaks and spills). Additionally, the construction of roads (both permanent and temporary) may channelize river systems and hinder fish migration routes between different habitats. For example, a recent study focused on the impacts of stream crossing structures in the North Slope oilfields near Prudhoe Bay indicated that 29% of the crossings evaluated restricted or completely blocked fish passage (Morris and Winters 2008).

Harvest:

Many fish species are harvested for subsistence and sport use within the North Slope study area. While commercial fishing in the area is currently relatively small, it has the potential to increase in the future.

Invasive species:

Invasive plant species have the potential to outcompete native aquatic and emergent vegetation. However, few invasive plant species have been documented within the North Slope study area and no aquatic species have yet been documented. *Elodea* spp. is an invasive aquatic plant that has recently been documented in south central Alaska and Chena slough, near Fairbanks. *Elodea* spp. generally invade and outcompete other aquatic plant species in slow moving streams or small, shallow lakes and ponds.

Attributes and Indicators

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating				Basis for Indicator Rating	Comments
				Poor	Fair	Good	Very Good		
Climate	Winter precipitation	Dec-Feb total precipitation	Fish overwintering habitat	Less precipitation			More precipitation	Specific thresholds are unknown	Increased winter precipitation could increase available overwintering habitat (by increasing the volume of water)
	Winter precipitation	Dec-Feb total precipitation	Fish overwintering habitat	More precipitation			Less precipitation	Specific thresholds are unknown	Increased precipitation could result in increased run-off and sedimentation negatively impacting habitat
	Summer temperature	Mean ambient air temperature (June-August)	Increased susceptibility to disease	Water temperature above 20 °C	Water temperature above 15°C		Water temperature below 15°C	Zuray et al. 2012-Thresholds based on salmonid studies and may not apply to all CEs	
	Temperature	Year-round temperature	Habitat Physiological stress	Water temperature increase of > 4°C	Water temperature increase of 2°C- 4°C		No temperature increase	Reist et al. 2006;Schiedek et al. 2007	Increased water temperatures could preclude some species from preferred habitat; increase physiological stress
	Temperature	Year-round temperature	Contaminant exposure					AMAP 2002; Thresholds unknown	Increased water temperatures allow for certain contaminants to become more bioavailable

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating				Basis for Indicator Rating	Comments
				Poor	Fair	Good	Very Good		
Climate	Frost-free days/Season length	Cumulative days with temps above 0 °C (Days between DOT and DOF)	Increased juvenile growth rates			Increased number of frost-free days		Reist et al. 2006-general thresholds	A longer ice-free season could improve the quality of feeding habitats with an increase in primary productivity due to longer periods of solar exposure
	Frost-free days/Season length	Cumulative days with temps above 0 °C (Days between DOT and DOF)	Increase fish feeding time; shifts in time of spawning			Increased number of frost-free days		Reist et al. 2006-general thresholds	A longer ice-free season will decrease the amount of time that fish spend overwintering and increase the amount of time that fish can spend feeding ;Spawning shifts to correspond with ice-free season
	Change in mean annual ground temperature at one meter (MAGT)	Permafrost thaw	Reduce habitat quality	From below -1m to above +1m			No Change	Lloyd et al 2003 (based on GIPL model); Bowden et al. 2008 (based on general effects)	Increased stream turbidity from erosion and runoff may reduce primary production and aquatic invertebrate populations, lowering the quality of fish feeding habitat and reduce spawning habitat
	Change in mean annual ground temperature at one meter (MAGT)	Permafrost thaw	Improve habitat quality	From -1m to above +1m			No Change	Lloyd et al 2003 (based on GIPL model); Bowden et al. 2008 (based on general effects)	Permafrost thaw may increase nutrient input into aquatic habitats thereby increasing primary production and invertebrate populations

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating				Basis for Indicator Rating	Comments
				Poor	Fair	Good	Very Good		
Fire	Fire frequency	Fire return interval	Feeding (summer) habitat	High return interval			Low return interval	Davis et al. 2013- Thresholds are general based on this study	Fires strip stabilizing vegetation from the landscape and increase erosion and runoff, resulting in higher sediment inputs to streams and lakes
	Fire frequency	Fire return interval	Feeding (summer) habitat	Low return interval		High return interval		Davis et al. 2013- Thresholds are general based on this study	Fire increases nutrient inputs
Anthropogenic development	Contaminated sites	Water quality	Habitat					Thresholds will depend on specific contaminants at a site and proximity to waterbodies	Oil contamination
	Road development	Water quality	Habitat	Numerous intersections with streams and lakes			No intersection with streams and lakes	Thresholds will depend on specific proximity of fish habitat to a site	Turbidity, metals and hydrocarbon contamination, temperature changes
	Habitat fragmentation	Road development	Habitat					Thresholds will depend on specific proximity of fish habitat to a site	Disrupt fish migratory movements; stranding events

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating				Basis for Indicator Rating	Comments
				Poor	Fair	Good	Very Good		
	Oil and gas activities	Water withdrawal	Habitat	Lakes used by fish			Lakes not used by fish	BLM 2006-general thresholds	Effect water quality, reduce spawning habitat for burbot and reduce overwintering and foraging habitat for all other fine-filter CEs.

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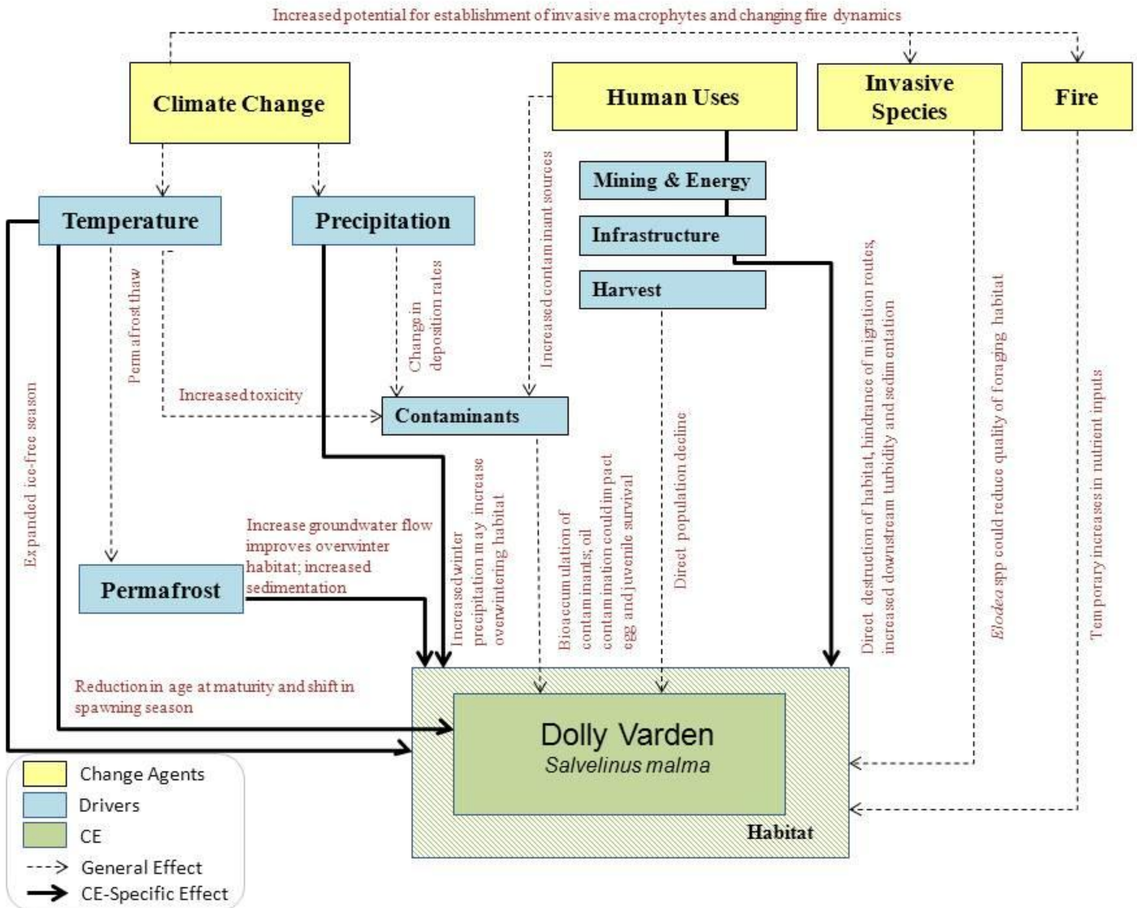
Dolly Varden (*Salvelinus malma*)

Background

Dolly Varden occur on the North Slope as lake-resident, stream resident, and anadromous populations although they are considered to be predominantly anadromous within the North Slope study area. Anadromous Dolly Varden are the most abundant and most commonly harvested for subsistence fisheries. Dolly Varden generally mature at five to nine years of age and can spawn multiple times throughout their lifetimes. Dolly Varden tagging studies have shown that anadromous fish maintain a strong fidelity to overwintering and spawning areas and that spawning typically occurs in overwintering areas (Viavant et al. 2005, ADF&G 2011). However, some Dolly Varden may overwinter in areas not connected to their natal streams (Crane et al. 2005). Major river drainages used by Dolly Varden for spawning, rearing, and overwintering habitat include the Colville, Kuparak, Canning, and Sagavanirktok (Scanlon 2012).

Dolly Varden use habitats associated with discharging groundwater for spawning, rearing, and overwintering. However, these habitats on the North Slope comprise a relatively small proportion of overall stream habitats and thus, are limiting to populations. Overwintering habitat is especially critical and limited to small streams with spring-fed areas. Spawning occurs from August through late September. Females lay eggs in small, dugout nests in stream gravel beds. Hatching of eggs generally occurs in March, and juvenile fish emerge from the gravel in late spring and after break-up, which generally begins in late May. Dolly Varden migrate to streams and river channels that were previously frozen, and to the nearshore coastal waters for feeding and rearing. Larger juvenile and adult fish consume salmon fry, salmon eggs, invertebrates, and small fish. Juveniles feed primarily on macroinvertebrates.

Conceptual Model



Climate Change:

Increasing annual temperatures will cause a general trend of permafrost thaw on the landscape level, increasing the depth of the soil active layer and the mean annual ground temperature. As a consequence, there will be an increase of erosion and runoff into lakes and streams. Similarly, lake drainage, as a consequence of permafrost thaw, is likely to increase as the depth of the active layer increases. The drainage of lakes related to permafrost thaw, will reduce available habitat for resident lake populations of Dolly Varden. On the other hand, permafrost thaw could increase groundwater flows in winter improving overwintering habitat and increasing overwintering survival for Dolly Varden. Permafrost thaw may increase nutrient input into aquatic habitats thereby increasing primary production and invertebrate populations (Bowden et al. 2008). Increased nutrient input will improve the quality of fish feeding habitat with the direct or indirect increased abundance of prey species (Reist et al. 2006). Increased sedimentation in streams will reduce the quality of spawning habitat for Dolly Varden because they rely on gravel substrate to hide their eggs.

With projected increased temperatures, the duration of the ice-free season will likely increase and improve the quality of feeding habitats as those habitats will remain ice-free for a longer period of time (Reist et al. 2006). Consequently, the age at maturity for Dolly Varden will likely decrease because individuals will be able to feed more during any single year. Spawning will shift later in the fall to correspond with the changes in the duration of the ice-free season. Warmer waters may also increase the prevalence of diseases and parasites (Reist et al. 2006).

Increased temperatures within the North Slope study area will have a significant impact on glacial stream systems. Glacial melt and runoff is an important source of late summer discharge to streams and rivers that provide sufficient flow that allows Dolly Varden to reach spawning and overwintering habitats (Nolan et al. 2011). With the loss of sufficient late summer discharge, overwintering habitat could become even more limited for Dolly Varden in streams directly influenced by glacier run-off (e.g., streams within the Brooks Range area). Furthermore, a decrease in discharge could negatively impact Dolly Varden that use glacial systems to complete their migrations from summer feeding areas to spawning and overwintering habitats.

A predicted increase in winter precipitation could potentially increase available overwintering habitat directly (by increasing the volume of water) and indirectly through the loss of snow insulation which would reduce ice thickness. Increased precipitation could also result in increased run-off and sedimentation to Dolly Varden habitat.

<u>Contaminants:</u>

Melting glaciers can release contaminants (that have accumulated from years of atmospheric deposition), including persistent organic pollutants and mercury, into streams and lakes where fish can readily absorb these pollutants (Blais et al. 2001). Dolly Varden commonly use glacial streams, especially in the Brooks Range area and therefore may be vulnerable to high exposure rates of contaminants as glaciers continue to melt. Furthermore, because Dolly Varden can be piscivorous during the juvenile and adult freshwater stages, they have the propensity to bioaccumulate and biomagnify organhochlorine and heavy metal contaminants.

<u>Anthropogenic Uses:</u>

Major construction, especially of roads will increase erosion and runoff leading to increased stream turbidity and sedimentation. Increased turbidity and sedimentation could have negative impacts on egg and juvenile survival. Road development at stream crossings could disrupt migratory pathways and alter access between key summering and wintering habitats. Much road development occurs during the winter which could have negative impacts on Dolly Varden overwintering habitat. Water removal and gravel extraction can have population-level effects on Dolly Varden due to the limited overwintering habitat on the North Slope.

<u>Harvest:</u>

Dolly Varden are an important subsistence resource to North Slope residents (Craig 1989). Overwintering and spawning populations also provide for sport fisheries. Dolly Varden represents approximately 40% of the total subsistence harvest fisheries in Kaktovik (Pedersen 2005). Recent Dolly Varden subsistence harvests for the North Slope area range from approximately 4,000–10,000 (Scanlon 2012). Recent estimated annual sport harvests are around 1,000 for the entire North Slope, catches are around 5,000, and total effort is around 5,000 angler days (Scanlon 2012). Annual average sport harvest of Dolly Varden for 2001–2012 was 5,053 fish and annual sport catch averaged between 18,000–20,000 (Scanlon 2012). Sport harvest of Dolly Varden on the North Slope is currently estimated to be within sustainable limits (Scanlon 2011).

Attributes and Indicators

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating				Basis for Indicator Rating	Comments
				Poor	Fair	Good	Very Good		
Climate	Winter precipitation	Dec-Feb total precipitation	Overwintering habitat	Less precipitation			More precipitation	Specific thresholds are unknown	Increased winter precipitation could increase available overwintering habitat (by increasing the volume of water)
	Winter precipitation	Dec-Feb total precipitation	Overwintering habitat	More precipitation			Less precipitation	Specific thresholds are unknown	Increased precipitation could result in increased run-off and sedimentation negatively impacting habitat
	Summer temperature	June-August mean monthly air temperature	Summer habitat	Warmer air temperature			No change in air temperatur	Nolan et al. 2011-general thresholds	Decrease in glacial melt run-off as a result of warming climate glacier retreat
	Summer temperature	June-August mean monthly air temperature	Parasite infections	Water temperature above 20 °C	Water temperature above 15°C		Water temperature below 15°C	Zuray et al. 2012-Thresholds based on salmonid studies	Warmer waters may increase the prevalence of diseases and parasites
	Frost-free days/Season length	Cumulative days with temps above 0 °C (Days between DOT and DOF)	Shift in spawning time			Increased number of frost-free days		Specific thresholds are unknown	Spawning will shift later in the fall to correspond with the time that aquatic habitats become ice-free

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating				Basis for Indicator Rating	Comments
				Poor	Fair	Good	Very Good		
Climate	Frost-free days/Season length	Cumulative days with temps above 0 °C (Days between DOT and DOF)	Juvenile growth			Increased number of frost-free days		Reist et al. 2006-general thresholds	The age at maturity for Dolly Varden will likely decrease because individuals will be able to feed more during any single year
	Change in mean annual ground temperature at one meter (MAGT)	Permafrost thaw	Loss of habitat for lake resident populations					Lloyd et al 2003 (based on GIPL model)	Lake drainage will result in loss of habitat or decline in lake area.
	Change in mean annual ground temperature at one meter (MAGT)	Permafrost thaw	Increased overwintering habitat						Increased ground flows in winter as a consequence of permafrost thaw could improve overwintering habitat for Dolly Varden
	Change in mean annual ground temperature at one meter (MAGT)	Permafrost thaw	Foraging habitat	From below -1m to above +1m			No Change	GIPL model, Lloyd et al 2003 (based on GPL model); Bowden et al. 2008 (based on general effects)	Increased nutrient input with permafrost thaw will improve feeding habitat by increasing primary productivity

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating				Basis for Indicator Rating	Comments
				Poor	Fair	Good	Very Good		
Anthropogenic development	Road development	Water quality	Habitat	Numerous intersections with streams and lakes			No intersection with habitats	Thresholds will depend on specific proximity of fish habitat to a site	Turbidity, metals and hydrocarbon contamination, temperature changes
Anthropogenic development	Habitat fragmentation	Road development	Habitat	Numerous intersections with streams and lakes			No intersection with habitats	Thresholds will depend on specific proximity of fish habitat to a site	Disrupt fish Dolly Varden movements; stranding events
	Contaminated sites	Water quality	Habitat					Thresholds will depend on specific contaminants at a site and proximity to waterbodies	Oil contamination
	Oil and gas activities	Water withdrawal	Habitat	Lakes used by Dolly Varden			Lakes not used by Dolly Varden	BLM 2006-general thresholds	Effect water quality, reduce foraging and overwintering habitat

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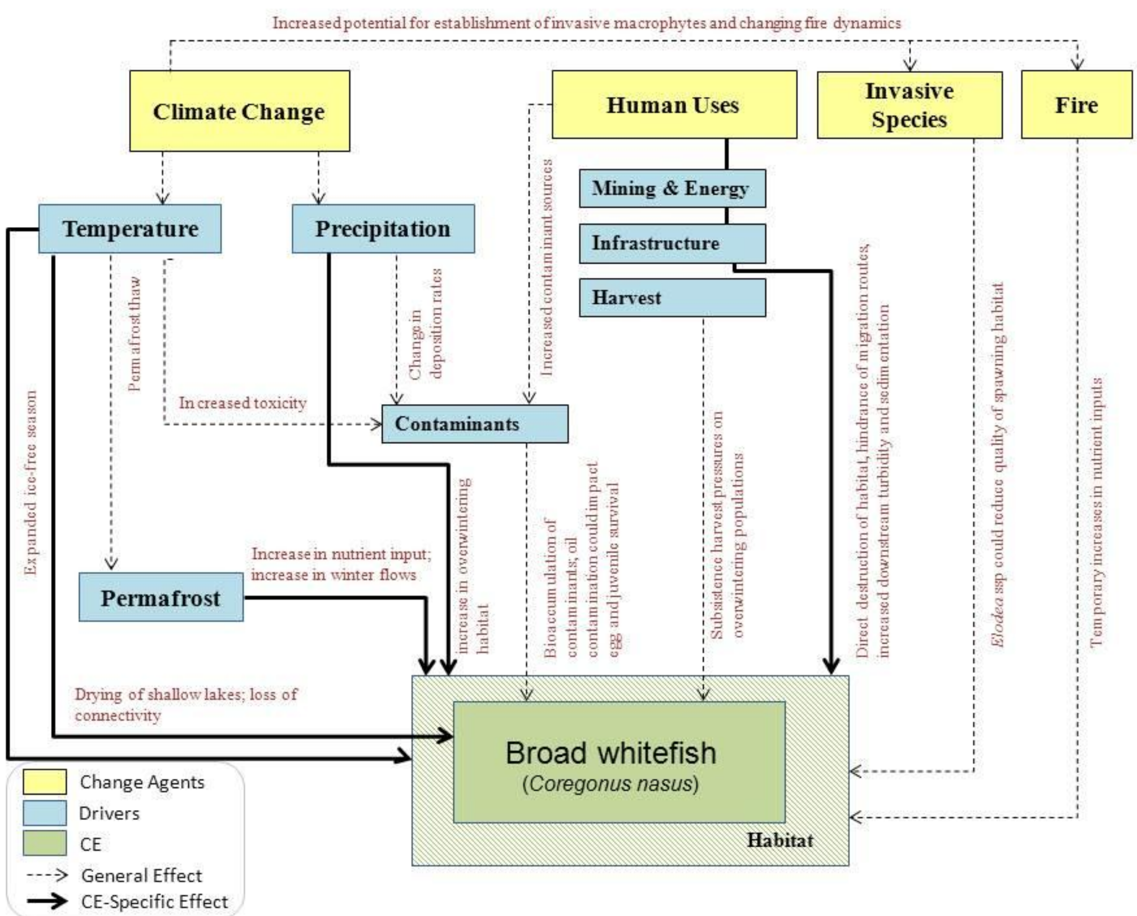
Broad whitefish (*Coregonus nasus*)

Background

Broad whitefish are typically anadromous, although freshwater resident populations have been documented in lakes and streams within the North Slope study area. Broad whitefish typically mature around four to five years of age and can live up to 20 years. Spawning occurs in late fall to early winter in gravel stream beds (ADF&G 1986). After spawning, broad whitefish migrate downstream to overwinter under the ice in deep freshwater pools in rivers and lakes (Morris 2006). Migration to their summer feeding areas in salt water begins during spring break up. The diet of broad whitefish is composed of marine and freshwater invertebrates.

Studies have documented the importance of small drainages with lake connectivity for broad whitefish summer habitat on the North Slope (Morris 2006). Suitable overwintering habitat is one of the most severe constraints on broad whitefish populations and the use of ephemeral streams to move into lake habitats for overwintering is especially important (Morris 2006). Important overwintering areas include: Teshepuk and Mayoriak Lakes, and Colville and Sagayoniak rivers (Morris 2006).

Conceptual Model



Climate Change:

Broad whitefish rely on productive shallow lakes for summer foraging and ephemeral stream systems to move into lake habitats for overwintering (Morris 2006). With projected increases in temperature and permafrost thaw, the potential for drying of shallow lakes is a concern for populations of broad whitefish on the North Slope. A loss of connectivity to lakes could have negative consequences for broad whitefish populations by reducing food availability and affecting the timing of migrations. Furthermore, shallow lakes that are commonly used as summer feeding habitats by broad whitefish are especially susceptible to increases in temperature and lake drying. Thus, broad whitefish that use these lakes could be exposed to lethal or near lethal temperatures during the summer and/or experience stranding events due to loss of connectivity from summer feeding habitats into overwintering habitats. If migratory corridors between highly productive foraging lakes and cooler river systems were reduced across the landscape, lake-feeding broad whitefish could experience increased summer mortality.

With projected increased temperatures, the duration of the ice-free season will likely increase. A longer ice-free season could improve the quality of feeding habitats as those habitats will likely experience an increase in primary productivity due to longer periods of solar exposure (Reist et al. 2006). The open water period is the primary feeding time for broad whitefish (Reist and Bond 1988) thus, the age at maturity will likely decrease because individuals will be able to feed more during any single year. With an earlier breakup period, egg development time would likely be reduced and it's possible that spawning will shift to later in the fall to correspond with the time that water temperature approaches 0 °C or the time that aquatic habitats become ice-free, respectively. Warmer waters may also increase the prevalence of diseases and parasites (Reist et al. 2006).

Permafrost thaw will likely increase groundwater flows in winter improving overwintering habitat for broad whitefish which will likely increase overwintering survival, at least temporarily. Permafrost thaw may increase nutrient input into aquatic habitats thereby increasing primary production and invertebrate populations (Bowden et al. 2008). Thus, increased nutrient input will improve the quality of fish feeding habitat with the direct or indirect increased abundance of prey species (Reist et al. 2006).

A predicted increase in winter precipitation could potentially increase available overwintering habitat directly (by increasing the volume of water) and indirectly through the loss of snow insulation which would reduce ice thickness. Increased precipitation could also result in increased run-off and sedimentation.

Contaminants:

As water temperature increases, certain contaminants become more bioavailable (e.g., mercury) and thus, exposure rates of contaminants in fish will likely increase with a warming climate (AMAP 2002). Broad whitefish is an important subsistence fish to residents on the North Slope, and exposure to toxic pollutants could reduce the value of broad whitefish as a subsistence resource. Because broad whitefish consume mostly lower trophic level species such as invertebrates, they are less likely to contain high levels of contaminants, compared to piscivorous species such as Dolly Varden and chum salmon. However, broad whitefish are a long-lived species and have the potential to bioaccumulate contaminants over time. Thus, the effects of contaminants on individual fish over time and human exposure of contaminants through consumption of fish is a potential concern.

Oil field operations have the potential to introduce contaminants to aquatic habitats, including broad whitefish habitats within the North Slope study area. Whereas, some contaminants such as organchlorines (e.g., PCBs, DDT, and POPs) and mercury have both local and distant anthropogenic sources, petroleum products are directly related to local activities. Spilled petroleum products may arise from activities such as drilling and transportation of personnel and materials. Contaminants on roads from vehicle leakage may runoff into drainages affecting water quality. Petroleum products may persist in aquatic environments for years after a spill or leak. Petroleum products can directly affect the health of fish by impacting their ability to adequately take up oxygen or through ingestion, which may compromise other physiological functions (Peterson et al. 2003). Oil contaminations can also severely impact egg, larvae, and juvenile survival because of their reduced capacity to leave the contaminated area (Brown et al. 2012).

Anthropogenic Uses:

Road development for oil and gas exploration and water withdrawal are considered to be the most important development concerns within the North Slope study area. Major construction, especially of roads will increase erosion and runoff leading to increased stream turbidity and sedimentation. Increased turbidity and sedimentation could have negative impacts on egg and juvenile survival (Brown et al. 2012). Road development at stream crossings could disrupt migratory pathways and alter access between key summering and wintering habitats. Due to the use of small drainages, including ephemeral streams, any development that would impede fish passage within these small drainages, could have negative impacts on broad whitefish populations within the North Slope study area (Morris 2006). Broad whitefish are considered potentially sensitive to water withdrawal activities, especially during the winter when habitat is most limiting (BLM 2006). Bridges and culverts used for development of oil production could affect broad whitefish habitat directly by increasing sedimentation or altering migration routes.
In addition to direct environmental changes resulting from road construction, roads increase human access to previously remote areas, which facilitates increased recreational use of resources.

Harvest:

Broad whitefish is one of the most heavily harvested subsistence fish species on the North Slope. Currently, no agency manages broad whitefish on the North Slope. The community of Nuiqsut operates subsistence fisheries year-round, although most fishing effort occurs in summer and fall. On the Colville delta, reported summer harvests have ranged from 3,000-4,000 broad whitefish.

Attributes and indicators

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating: Poor	Indicator Rating: Fair	Indicator Rating: Good	Indicator Rating: Very Good	Basis for Indicator Rating	Comments
Climate	Winter precipitation	Dec-Feb total precipitation	Overwintering habitat	Less precipitation			More precipitation	Specific thresholds are unknown	Increased winter precipitation could increase available overwintering (by increasing the volume of water)
	Winter precipitation	Dec-Feb total precipitation	Overwintering habitat	More precipitation			Less precipitation	Specific thresholds are unknown	Increased precipitation could result in increased run-off and sedimentation negatively impacting habitat
	Summer temperature	June-August mean monthly air temperature	Summer habitat	Warmer temperature			No change in temperature	Specific thresholds are unknown	Loss of lake connectivity; lake drying
	Summer temperature	June-August mean monthly air temperature	Parasite infections	Water temperature above 20 °C	Water temperature above 15°C		Water temperature below 15°C	Zuray et al. 2012- Thresholds based on salmonid studies	Warmer waters may also increase the prevalence of diseases and parasites
	Frost-free days/Season length	Cumulative days with temps above 0 °C (Days between DOT and DOF)	Egg development and shifts in spawning time			Increased number of frost-free days		Specific thresholds are unknown	With an earlier breakup period, egg development time would likely be reduced and it's possible that spawning will shift to later in the fall

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating				Basis for Indicator Rating	Comments
				Poor	Fair	Good	Very Good		
Climate	Frost-free days/Season length	Cumulative days with temps above 0 °C (Days between DOT and DOF)	Juvenile growth			Increased number of frost-free days		Reist and Bond 1988; Reist 2006-general thresholds	The age at maturity for broad whitefish will likely decrease because individuals will be able to feed more during any single year
	Change in mean annual ground temperature at one meter (MAGT)	Permafrost thaw	Overwintering habitat			Increased rates of thaw		Specific thresholds are unknown	Increased ground flows in winter as a consequence of permafrost thaw could improve overwintering habitat
	Change in mean annual ground temperature at one meter (MAGT)	Permafrost thaw	Foraging habitat	From below -1m to above +1m			No Change	Lloyd et al 2003 (based on GIPL model); Bowden et al. 2008 (based on general effects)	Increased nutrient input with permafrost thaw will improve feeding habitat by increasing primary productivity
Anthropogenic development	Road development	Water quality	Habitat	Numerous intersections with habitats			No intersection with habitats	Thresholds will depend on specific proximity of fish habitat to a site	Turbidity, metals and hydrocarbon contamination, temperature changes

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating				Basis for Indicator Rating	Comments
				Poor	Fair	Good	Very Good		
Anthropogenic development	Habitat fragmentation	Road development	Habitat	Numerous intersections with habitats			No intersection with habitats	Morris and Winters 2008-thresholds are general	Disrupt fish migratory movements; direct destruction of habitat, erosion, sedimentation
	Oil and gas activities	Water withdrawal	Habitat disturbance or loss	Lakes used by broad whitefish			Lakes not used by broad whitefish	BLM 2006-thresholds are general	Effect water quality, reduce spawning habitat and reduce overwintering habitat
	Contaminated sites	Water quality	Habitat					Thresholds will depend on specific contaminants at a site and proximity to waterbodies	Oil contamination could reduce egg survival and spawning habitat

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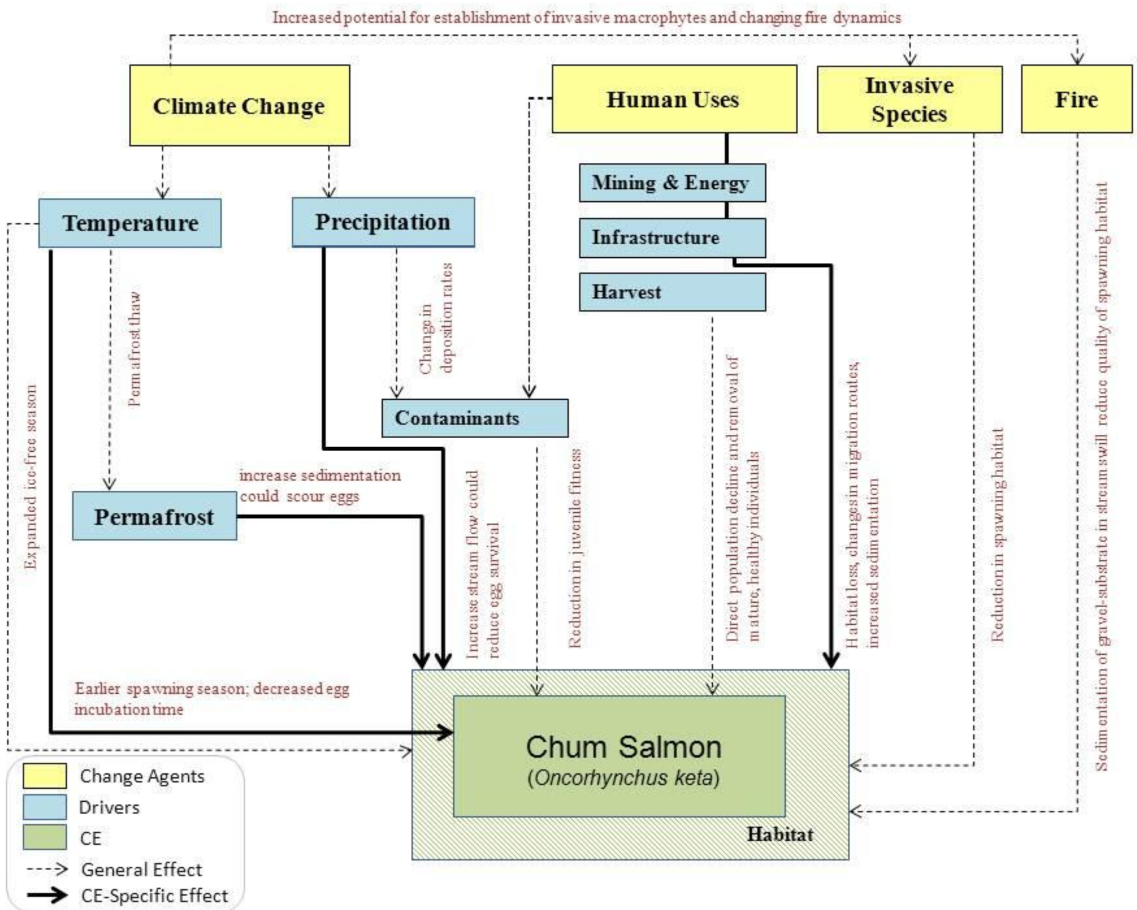
Chum Salmon (*Oncorhynchus keta*)

Background

Chum salmon are anadromous fish that typically spend the summers in fresh water and migrate to the ocean where they spend two to four winters at sea. However, little is known about the overwintering habits of chum salmon that spawn on the North Slope. It is assumed that chum salmon either winter in the Beaufort Sea, offshore deep under pack ice or that they overwinter in freshwater or brackish habitats such as river mouths, spring-fed streams, and pockets of flowing water in large rivers that stay fluid throughout winter, or beaver ponds, which are warm water refugia (Irvine et al. 2009).
As adults, chum salmon almost always return to spawn in their natal stream to spawn in late summer or early fall (Irvine et al. 2009). Embryos hatch after 3–4 months, depending on water temperature and remain in the gravel while continuing to absorb nutrients from the egg yolk for an additional 60–90 days before emerging (Morrow 1980). Fry emerge from the gravel during spring (April–May) and migrate to the ocean within days or a few weeks after hatching (Salo 1991). Juvenile chum salmon that hatch far upriver begin feeding on insect larvae while still moving toward the sea.

Spawning populations of chum salmon have been documented in the Colville River and elsewhere on the North Slope (Bendock 1979, Craig and Haldorson 1986), but it is unknown whether these spawning events sustain consistent runs of chum. Winter temperatures of arctic marine waters are generally lethal for salmon. Groundwater-fed streams are usually many degrees warmer than other streams on the North Slope, thus the eggs may be able to survive. The lower thermal temperature limit for chum salmon is 2.7°C. (Azumaya et al. 2007). Typical Arctic stream temperatures average between 0 and 0.5 °C in winter months, but pockets of groundwater provide shelter with temperatures between 2 and 5 °C throughout winter months (Craig and Haldorson 1986). Warming conditions may be producing more suitable habitat for salmon in the Arctic.

Conceptual Model



Climate Change:

Water flow through the substrate, water temperature, and dissolved oxygen concentration (Maclean 2003) are important factors that influence redd site selection by chum salmon. Increased permafrost and snow melt may increase the rate of stream discharge and the potential for scour and sedimentation of chum salmon redds (Lisle 1989). Increased precipitation (especially in winter) could have similar negative impacts on chum salmon spawning habitat by increasing the potential scouring of redds and erosion of streambanks. Time of fry emergence is related to temperature during incubation (Salo 1991) and thus, changes during the early part of incubation can affect time of emergence. As temperatures increase, egg incubation rates will increase and time to emergence and migration will decrease. Chum salmon may benefit more directly from increases in water temperatures because they tend to select warmer and stable water temperatures for spawning habitat (Maclean 2003). Chum salmon need initial incubation temperatures about 4.0 °C for successful early embryonic development (Raymond 1981; Beacham et al. 1988). Warmer water temperatures in fall chum spawning sites may be important in controlling the timing of their emergence in relation to the availability of their prey (Cushing 1990; Gotceitas et al. 1996). However, an increase in water temperatures (coupled with low flow as a consequence of decreased summer precipitation) could cause higher fish densities and depleted oxygen concentrations, resulting in high pre-spawning mortality (Murphy 1985).

Anthropogenic Uses:

The majority of the life of chum salmon occurs in the marine environment, thus the largest impact from development of roads and oil and gas operations would affect spawning habitat since juveniles do not rear in streams. However, if adult chum salmon overwinter in freshwater habitats on the North Slope, then overwintering populations could be affected by winter development activities. Infrastructure and development for oil and gas activities such as road construction and culverts have been reported to have detrimental effects on salmon spawning habitat. In particular, road construction has the potential to cause high sediment loads in streams (Beschta 1978). Similarly, stream culverts at road crossings may hinder migration routes.

Harvest:

Subsistence and sport harvest studies for chum salmon on the North Slope are limited. However, estimates of sport chum salmon harvest on the North Slope (Brooks Range drainages) from 1994–2004 was less than 15 individuals for all years, except for 2000 when 763 individuals were reportedly harvested (Jennings et al. 2007). A recent study in Elsoon Lagoon documented the harvest of 483 chum salmon from Elsoon Lagoon during 20 July–31 August, 2008 (North Slope Borough et al. 2009).

Attributes and Indicators

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating: Poor	Indicator Rating: Fair	Indicator Rating: Good	Indicator Rating: Very Good	Basis for Indicator Rating	Comments
Climate	Winter precipitation	Nov-Dec total precipitation	Spawning habitat	More precipitation			Less precipitation	Lisle 1989- thresholds general	Increased precipitation could result in increased run-off and scour redds
	Fall temperature	Mean ambient Fall air temperature (Sept-Dec)	Chum salmon embryonic development	Water temperature below 0°C	Water temperature between 0°C -4.0°C	Water temperature around 4.0 °C	Water temperature between 4.0 °C -10 4.0 °C	Morrow 1980; Raymond 1981; Beacham et al. 1988	Chum salmon need initial incubation temperatures about 4.0 °C for successful early embryonic development; warmer water temperatures may reduce hatch time
	Fall temperature	Mean Sept air temperature	Pre-spawning mortality	Water temperature above 20°C	Water temperature above 15°C			Murphy 1985	Pre-spawning mortality related to increased temperatures
	Change in mean annual ground temperature at one meter (MAGT)	Permafrost thaw	Spawning habitat	From below -1m to above +1m			No Change	GIPL model, Lloyd et al 2003 (based on GPL model); Lisle 1989 (based on general effects)	Increased permafrost thaw could cause scour of salmon redd's

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating				Basis for Indicator Rating	Comments
				Poor	Fair	Good	Very Good		
Climate	Summer temperature	June-August mean monthly air temperature	Parasite infections	Water temperature above 20°C	Water temperature above 15°C	Water temperature around 15°C	Water temperature below 15°C	Zuray et al. 2012	Warmer waters may increase the prevalence of diseases and parasites
Anthropogenic development	Road development	Water quality	Spawning habitat	Numerous intersections with streams			No intersection with streams	Thresholds will depend on specific proximity of fish habitat to a site	Turbidity, metals and hydrocarbon contamination, temperature changes from impoundment; overall effects on spawning habitat
	Habitat fragmentation	Road development	Spawning habitat	Numerous intersections with streams			No intersection with streams	Morris and Winters 2008: thresholds are general	Disrupt fish migratory movements; direct destruction of habitat, erosion, sedimentation
	Contaminated sites	Water quality	Habitat					Thresholds will depend on specific contaminants at a site and proximity to waterbodies	Oil contamination could reduce egg survival and spawning habitat

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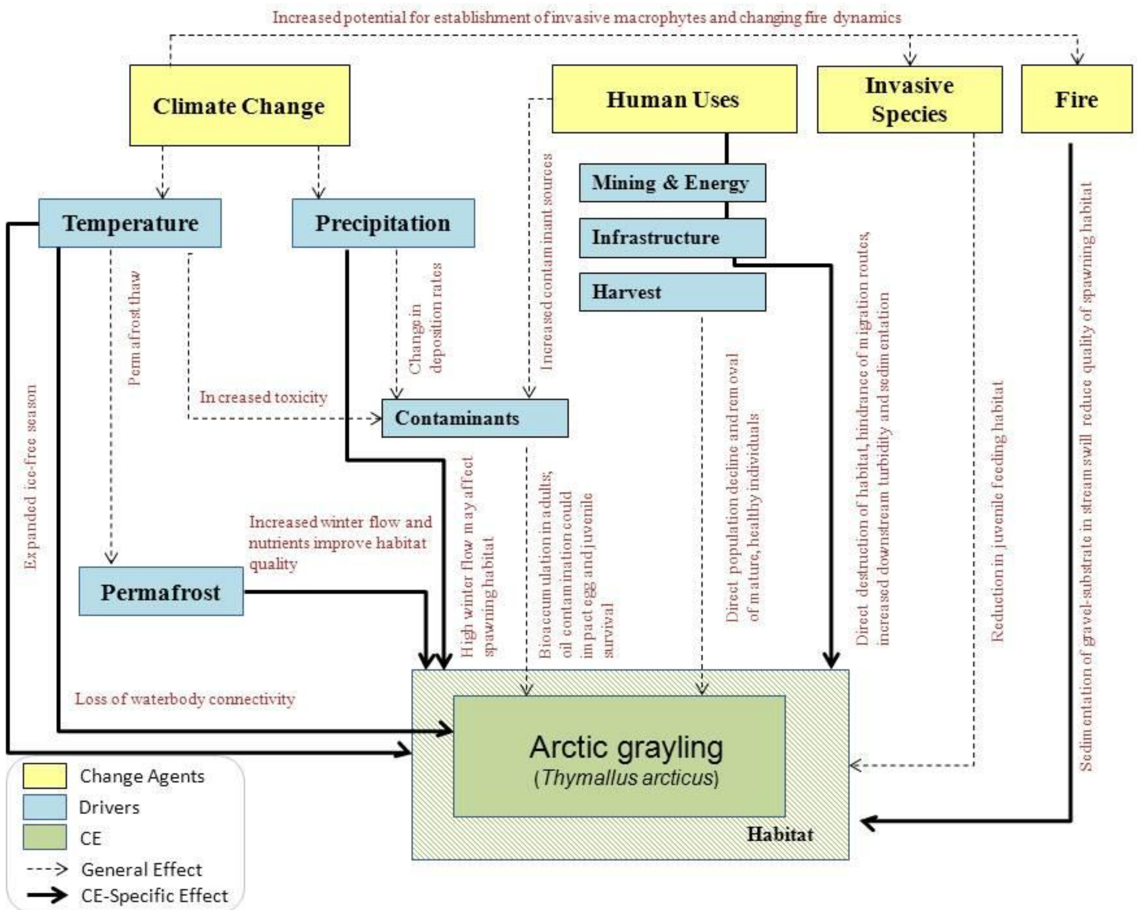
Artic Grayling (*Thymallus arcticus*)

Background

Arctic grayling are one of the most widespread fish species within the North Slope study area and are found exclusively in fresh water throughout the year. Arctic grayling are well adapted to the rigors of the arctic climate as they spend their entire life cycle within aquatic habitats on the North Slope. They can be migratory or relatively sedentary and remain in the same section of a stream year round. Similar to most other arctic fishes, available overwintering habitat is critical to their survival and is considered to be the major limiting factor for populations of Arctic grayling. Their tolerance of low dissolved oxygen levels allows grayling to survive the long winters in areas where many other species would perish. After spring break-up, Arctic grayling begin movements into streams and rivers that were previously frozen. Glacial rivers in the Brooks Range area are important migration corridors to tundra streams where grayling spawn and rear. Arctic grayling typically spawn in May and June in riffle areas of streams. After spawning, they move from smaller streams to the main streams and rivers where they spend the summer. Some Arctic grayling demonstrate strong site fidelity, returning every year to the same spawning and feeding areas (Morrow 1980). Juveniles emerge from the gravel in late June and early July and remain in the foothill streams throughout the summer. In late fall (before freeze-up), Arctic grayling move into overwintering areas in clear river channels associated with year round springs and deep pools (West et al. 1992). Arctic grayling are considered generalists, but primarily consume macroinvertebrates (Hobbie et al.1995). They will also eat salmon eggs and out-migrating salmon smolts. Grayling mature between the age of six and nine years and can live for up to 30 years.

Arctic grayling require colder water temperatures than most other fish with thermal maximum temperatures for adults around 20–25 °C (Stewart et al. 2007). For adults, temperatures above 15 °C are considered to induce stress, and temperatures greater than 20 °C cannot be tolerated for long without mortality. However, juveniles can tolerate warmer waters (between 10–20 °C). Thus water temperature of summer rearing and feeding habitats is an important determinant of the summer distribution of Arctic grayling, such that larger grayling tend to be found in the cooler upper reaches of rivers, whereas smaller grayling tend to be located in warmer downstream reaches.

Conceptual Model



Climate change:

With projected increased temperatures, the duration of the ice-free season will likely increase. A longer ice-free season could improve the quality of feeding habitats as those habitats will likely experience an increase in primary productivity due to longer periods of solar exposure (Reist et al. 2006). Permafrost thaw will likely increase groundwater flows in winter improving overwintering habitat for Arctic grayling which will likely increase overwintering survival, at least temporarily. Permafrost thaw may increase nutrient input into aquatic habitats thereby increasing primary production and invertebrate populations (Bowden et al. 2008). Thus, increased nutrient input will improve the quality of fish feeding habitat with the direct or indirect increased abundance of prey species (Reist et al. 2006). A predicted increase in winter precipitation could potentially increase available overwintering habitat directly (by increasing the volume of water) and indirectly through the loss of snow insulation which would reduce ice thickness. Increased precipitation could also result in increased run-off and sedimentation.

Increased temperatures (coupled with increased evapotranspiration) could increase drying stream and lake habitats and limit access to spawning and overwintering habitats. Even in areas where permafrost thaw may increase groundflows, water temperatures especially during the summer could result in the loss of connectivity (Deegan and Peterson 1992) which could impede arctic grayling from accessing preferred spawning or overwintering areas and/or force them into less preferred habitats. Warmer waters may also increase the prevalence of diseases and parasites (Reist et al. 2006).

Contaminants:

As water temperature increases, certain contaminants become more bioavailable (e.g., mercury) and thus, exposure rates of contaminants in fish will likely increase with a warming climate (AMAP 2002). Similar to broad whitefish, Arctic grayling consume mostly lower trophic level species such as invertebrates, and are less likely to contain high levels of contaminants (e.g., heavy metals and organohlorines), compared to piscivorous species such as Dolly Varden and chum salmon. However, because Arctic grayling are a long-lived species they have the potential to bioaccumulate contaminants over time and may concentrate levels of contaminants that represent a concern for individual fish as well as wildlife and humans that consume them.

Oil field operations have the potential to introduce contaminants to aquatic habitats within the North Slope study area. Whereas, some contaminants such as organchlorines (e.g., PCBs, DDT, and POPs) and mercury have both local and distant anthropogenic sources, petroleum products are directly related to local activities. Spilled petroleum products may arise from activities such as drilling and transportation of personnel and materials. Contaminants on roads from vehicle leakage may runoff into drainages affecting water quality. Petroleum products may persist in aquatic environments for years after a spill or leak and can directly affect the health of fish by impacting their ability to adequately take up oxygen or through ingestion, which may compromise other physiological functions (Peterson et al. 2003). Oil contaminations can also severely impact egg, larvae, and juvenile survival because of their reduced capacity to leave the contaminated area.

Bridges and culverts used for development of oil production could affect Arctic grayling habitat directly by increasing sedimentation or altering migration routes. Additionally, road development will provide access for humans to utilize streams or reaches previously inaccessible could potentially increase fishing pressure in local streams.

Anthropogenic Uses:

Road development for oil and gas exploration and water withdrawal are considered to be the most important development concerns within the North Slope study area. Oil exploration typically occurs during winter months which could have negative impacts on Arctic grayling overwintering populations. Arctic grayling are considered potentially sensitive to water withdrawal activities, especially during the winter when habitat is most limiting (BLM 2006). Road development at stream crossings could disrupt migratory pathways and alter access between key summering and wintering habitats. Due to the use of small drainages, including ephemeral streams, any development that would impede fish passage within these small drainages, could have negative impacts on Arctic grayling populations within the North Slope study area (Morris 2006). Additionally, because Arctic grayling growth rates are low and recruitment is variable they may not respond to disturbance well (Buzby and Deegan 2000). In addition to direct environmental changes resulting from road construction, roads increase human access to previously remote areas, which facilitates increased recreational use of resources.

Harvest:

Arctic grayling is an important subsistence species within the North Slope study area. Sport fishing effort is generally light, but variable, with most effort focused on streams and lakes along the Dalton Highway (Scanlon 2012). Estimated harvest of Arctic grayling within the North Slope was 2,204 in 2011 and the 10-year average was 3,028 (Scanlon 2012). Arctic grayling catch in 2011 was estimated around 12,000 fish (Scanlon 2012).

Attributes and Indicators

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating				Basis for Indicator Rating	Comments
				Poor	Fair	Good	Very Good		
Climate	Winter precipitation	Dec-Feb total precipitation	Overwintering habitat	Less precipitation			More precipitation	Specific thresholds are unknown	Increased winter precipitation could increase available overwintering (by increasing the volume of water)
	Winter precipitation	Dec-Feb total precipitation	Overwintering habitat	More precipitation			Less precipitation	Specific thresholds are unknown	Increased precipitation could result in increased run-off and sedimentation negatively impacting habitat
	Summer temperature	June-August mean monthly air temperature	Adult survivorship	Water temperature between 20°C-25°C	Water temperature above 20°C		Water temperature below 15°C	Stewart et al. 2007	Thermal stress
	Summer temperature	June-August mean monthly air temperature	Parasite infections	Water temperature above 20 °C	Water temperature above 15°C		Water temperature below 15°C	Zuray et al. 2012- Thresholds based on salmonid studies	Warmer waters may increase the prevalence of diseases and parasites
	Frost-free days/Season length	Cumulative days with temps above 0 °C (Days between DOT and DOF)	Egg development and shifts in spawning time			Increased number of frost-free days		Specific thresholds are unknown	With an earlier breakup period, egg development time would likely be reduced and it's possible that spawning will shift to later in the fall

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating				Basis for Indicator Rating	Comments
				Poor	Fair	Good	Very Good		
Climate	Frost-free days/Season length	Cumulative days with temps above 0 °C (Days between DOT and DOF)	Juvenile growth			Increased number of frost-free days		Reist and Bond 1988; Reist 2006-general thresholds	The age at maturity for arctic grayling will likely decrease because individuals will be able to feed more during any single year
	Change in mean annual ground temperature at one meter (MAGT)	Permafrost thaw	Overwintering habitat			Increased rates of thaw		Specific thresholds are unknown	Increased ground flows in winter as a consequence of permafrost thaw could improve overwintering habitat
	Change in mean annual ground temperature at one meter (MAGT)	Permafrost thaw	Foraging habitat	From below -1m to above +1m			No Change	GIPL model, Lloyd et al 2003 (based on GPL model); Bowden et al. 2008 (based on general effects)	Increased nutrient input with permafrost thaw will improve feeding habitat by increasing primary productivity
Anthropogenic development	Road development	Water quality	Habitat	Numerous intersections with habitats			No intersection with habitats	Thresholds will depend on specific proximity of fish habitat to a site	Turbidity, metals and hydrocarbon contamination, temperature changes

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating				Basis for Indicator Rating	Comments
				Poor	Fair	Good	Very Good		
Anthropogenic development	Habitat fragmentation	Road development	Habitat	Numerous intersections with habitats			No intersection with habitats	Morris and Winters 2008: thresholds are general	Disrupt fish migratory movements; direct destruction of habitat, erosion, sedimentation
	Oil and gas activities	Water withdrawal	Habitat disturbance or loss	Lakes used by artic grayling			Lakes not used by arctic grayling	BLM 2006- Thresholds are general	Effect water quality, reduce spawning habitat and reduce overwintering habitat
	Contaminated sites	Water quality	Habitat					Thresholds will depend on specific contaminants at a site and proximity to waterbodies	Oil contamination could reduce egg survival and spawning habitat

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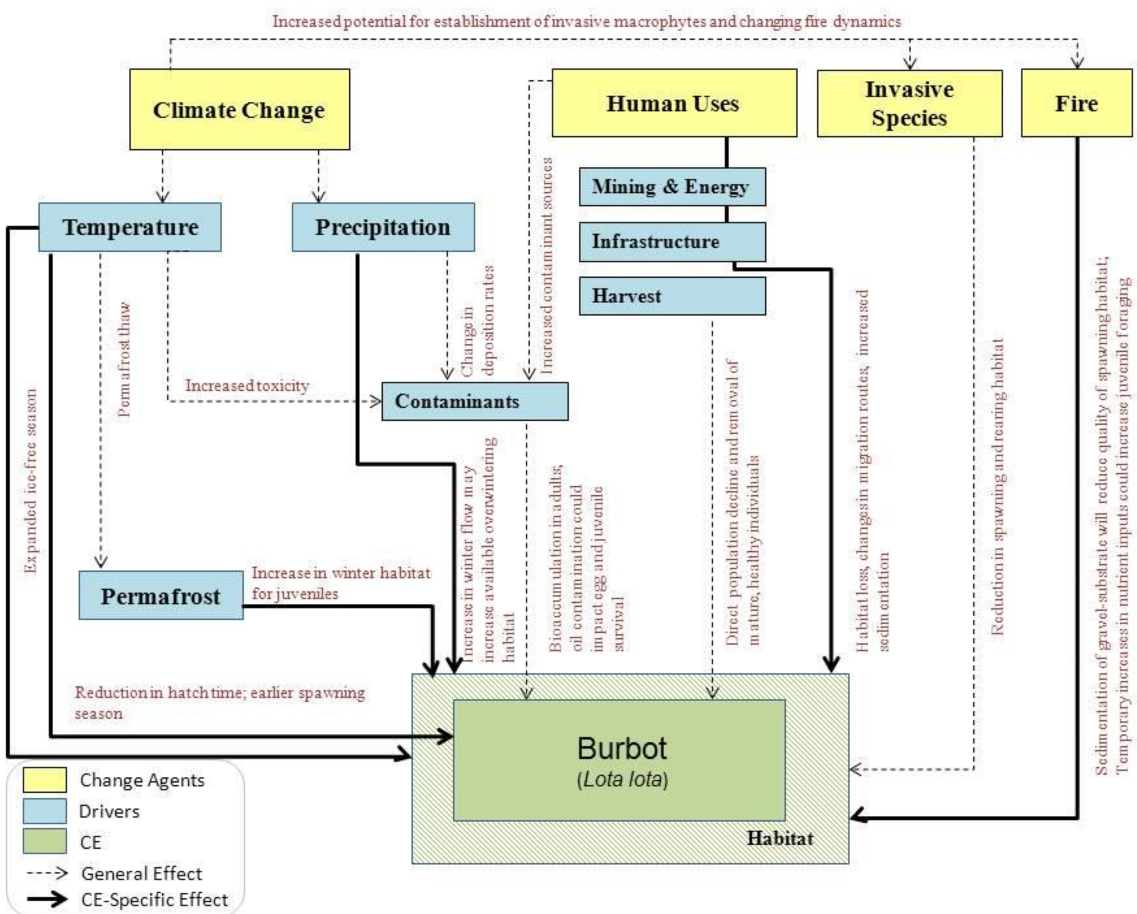
Burbot (*Lota lota*)

Background

Burbot are commonly found in well oxygenated streams and deep lakes (Morris 2003). Burbot are widespread in distribution throughout the North Slope study area, but their abundance is considered relatively low. However, the low abundance of burbot may be attributed to inefficient sampling gear and thus their distribution and abundance is likely underestimated for this area. Migratory patterns are not well known, but in general, burbot are rather sedentary fish except for movements between feeding and spawning areas (Morrow 1980). Burbot are unique in that they spawn under the ice, usually between January and February and fry hatch in March or April. During spawning, adults will gather in large groups and form a writhing mass with a few females at the center, surrounded by many males (Cahn 1936). Burbot mature in six to seven years and are a relatively long-lived species that can live up to 20 years. Optimal water temperature for burbot is reported at 15.6–18.3 °C (Scott and Crossman 1973). Juveniles feed on insects for the first few years, and then shift to a mostly piscivorous diet as adults (Morrow 1980). Although considered relatively sluggish in nature, burbot are voracious predators that feed at night. Similar to most other fish species on the North Slope, overwintering habitat is a major factor constraining burbot populations.

Conceptual Model



Climate Change:

Burbot are especially well adapted to cold water temperatures and increases in water temperature as a result of climate change could negatively impact burbot populations (Jackson et al. 2008). Warmer air temperatures will increase the length of the ice-free season to a later freeze-up date and an earlier thaw date. A lengthening of the duration of the ice free season could have an impact on the timing of spawning and egg hatching for burbot on the North Slope. Burbot eggs need approximately 71 days with temperatures between 0–3.6 °C to hatch (McCrimmon 1959). Thus, an increase in temperature may reduce hatching time and increase the amount of time that fish can spend feeding. As a consequence, the age at maturity for burbot may decrease because individuals will be able to feed more during any single year. Changes in water temperatures can also alter the timing of life history events, such as sexual maturation and timing of migration and spawning (Reist et al. 2006). An increase in winter precipitation could potentially increase available overwintering habitat directly (by increasing the volume of water) and indirectly through the loss of snow insulation which would reduce ice thickness. However, a reduction in ice thickness could have negative impacts on spawning populations since burbot spawn under the ice during winter. Warmer waters may also increase the prevalence of diseases and parasites (Reist et al. 2006).

Contaminants:

As water temperature increases, certain contaminants become more bioavailable (e.g., mercury) and exposure rates of contaminants in fish will likely increase. Studies in Arctic Canada have documented high concentrations of mercury and PCB's in burbot (Carrie et al. 2010). Because these contaminants bioaccumulate and biomagnify they have the potential to accumulate levels that pose a direct health risk to humans and wildlife that consume them. Warming temperatures within the North Slope study area may further exacerbate contaminants exposure in burbot within this region by both releasing snowpack- and permafrost-entrained mercury, and by enhancing conditions that facilitate methylmercury production (AMAP 2002). Future increases in mercury concentrations in aquatic habitat could pose a health risk to individual fish and potentially reduce the value of burbot as a subsistence resource.

Oil field operations have the potential to introduce contaminants to aquatic habitats within the North Slope study area. Whereas, some contaminants such as organchlorines (e.g., PCBs, DDT, and POPs) and mercury have both local and distant anthropogenic sources, petroleum products are directly related to local activities. Spilled petroleum products may arise from activities such as drilling and transportation of personnel and materials. Contaminants on roads from vehicle leakage may runoff into drainages affecting water quality. Petroleum products may persist in aquatic environments for years after a spill or leak and can directly affect the health of fish by impacting their ability to adequately take up oxygen or through ingestion, which may compromise other physiological functions (Peterson et al. 2003). Oil contaminations can also severely impact egg, larvae, and juvenile survival because of their reduced capacity to leave the contaminated area.

Anthropogenic Uses:

Most development on the North Slope is related to oil and gas industries. Habitat alterations to stream flow or changes to underlying sediments caused by stream crossings can lead to changes in water temperature, turbidity, and dissolved ion concentrations, which in turn could have negative impacts on burbot populations. Major construction, especially of roads will increase erosion and runoff leading to increased stream turbidity and sedimentation, and could introduce contaminates into these habitats (e.g., vehicular leaks and spills). Because burbot spawn during the winter, water withdrawals from lakes could have negative impacts on spawning populations. For example, water removal and gravel extraction could have population-level effects on burbot by disrupt spawning activities and/or or destroying spawning and overwinter habitat.

Harvest:

Ice-fishing for burbot during winter is a popular fishing practice on the North Slope. Sport fisheries of burbot occur throughout the North Slope area, but are relatively modest compared to other fish species. The largest fisheries occur in the Copper River area. Burbot sport fisheries increased from 1977–1983 by 30% annually (across the state) as a result of increased access to fishing sites and increased human population related to the construction of the Trans-Alaska Pipeline (Stapanian et al. 2010). Statewide harvest from 2002–2011 average 5,600 fish with no apparent trend during that time period. Little is known of the burbot subsistence fisheries on the North Slope.

Attributes and Indicators

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating				Basis for Indicator Rating	Comments
				Poor	Fair	Good	Very Good		
Climate	Winter precipitation	Dec-Feb total precipitation	Spawning habitat	Less precipitation			More precipitation	Specific thresholds are unknown	Increased winter precipitation could increase available overwintering (by increasing the volume of water)
	Summer temperature	June-August mean monthly air temperature	Summer habitat	Warming water temperatures			No change in water temperature	Specific thresholds are unknown	Loss of lake connectivity; lake drying
	Summer temperature	June-August mean monthly air temperature	Parasite infections	Water temperature above 20 °C	Water temperature above 15°C		Water temperature below 15°C	Zuray et al. 2012- Thresholds based on salmonid studies	Warmer waters may also increase the prevalence of diseases and parasites
	Frost-free days/Season length	Cumulative days with temps above 0 °C (Days between DOT and DOF)	Egg development and juvenile growth	Water temperature below 0°C	Water temperature below 3.6°C	Water temperature around 3.6°C	Water temperature above 3.6°C	McCrimmon 1959	Increased temperature may reduce hatching time and increase the amount of time that fish can spend feeding

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating				Basis for Indicator Rating	Comments
				Poor	Fair	Good	Very Good		
Climate	Frost-free days/Season length	Cumulative days with temps above 0 °C (Days between DOT and DOF)	Juvenile growth			Increased number of frost-free days		Reist and Bond 1988; Reist 2006-general thresholds	The age at maturity for burbot will likely decrease because individuals will be able to feed more during any single year
Climate	Change in mean annual ground temperature at one meter (MAGT)	Permafrost thaw	Overwintering habitat			Increased rates of thaw		Specific thresholds are unknown	Increased ground flows in winter as a consequence of permafrost thaw could improve overwintering habitat
Climate	Change in mean annual ground temperature at one meter (MAGT)	Permafrost thaw	Foraging habitat	From below -1m to above +1m			No Change	GIPL model, Lloyd et al 2003 (based on GPL model); Bowden et al. 2008 (based on general effects)	Increased nutrient input with permafrost thaw will improve feeding habitat by increasing primary productivity
Anthropogenic development	Road development	Water quality	Habitat	Numerous intersections with habitats			No intersection with habitats	Thresholds will depend on specific proximity of fish habitat to a site	Turbidity, metals and hydrocarbon contamination, temperature changes

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating				Basis for Indicator Rating	Comments
				Poor	Fair	Good	Very Good		
Anthropogenic development	Habitat fragmentation	Road development	Habitat	Numerous intersections with habitats			No intersection with habitats	Morris and Winters 2008- thresholds are general	Disrupt fish migratory movements; direct destruction of habitat, erosion, sedimentation
	Oil and gas activities	Water withdrawal	Habitat disturbance or loss	Lakes used by burbot			Lakes not used by burbot	BLM 2006- thresholds are general	Effect water quality, reduce spawning habitat and reduce overwintering habitat
	Contaminated sites	Water quality	Habitat					Thresholds will depend on specific contaminants at a site and proximity to waterbodies	Oil contamination could reduce egg survival and spawning habitat

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